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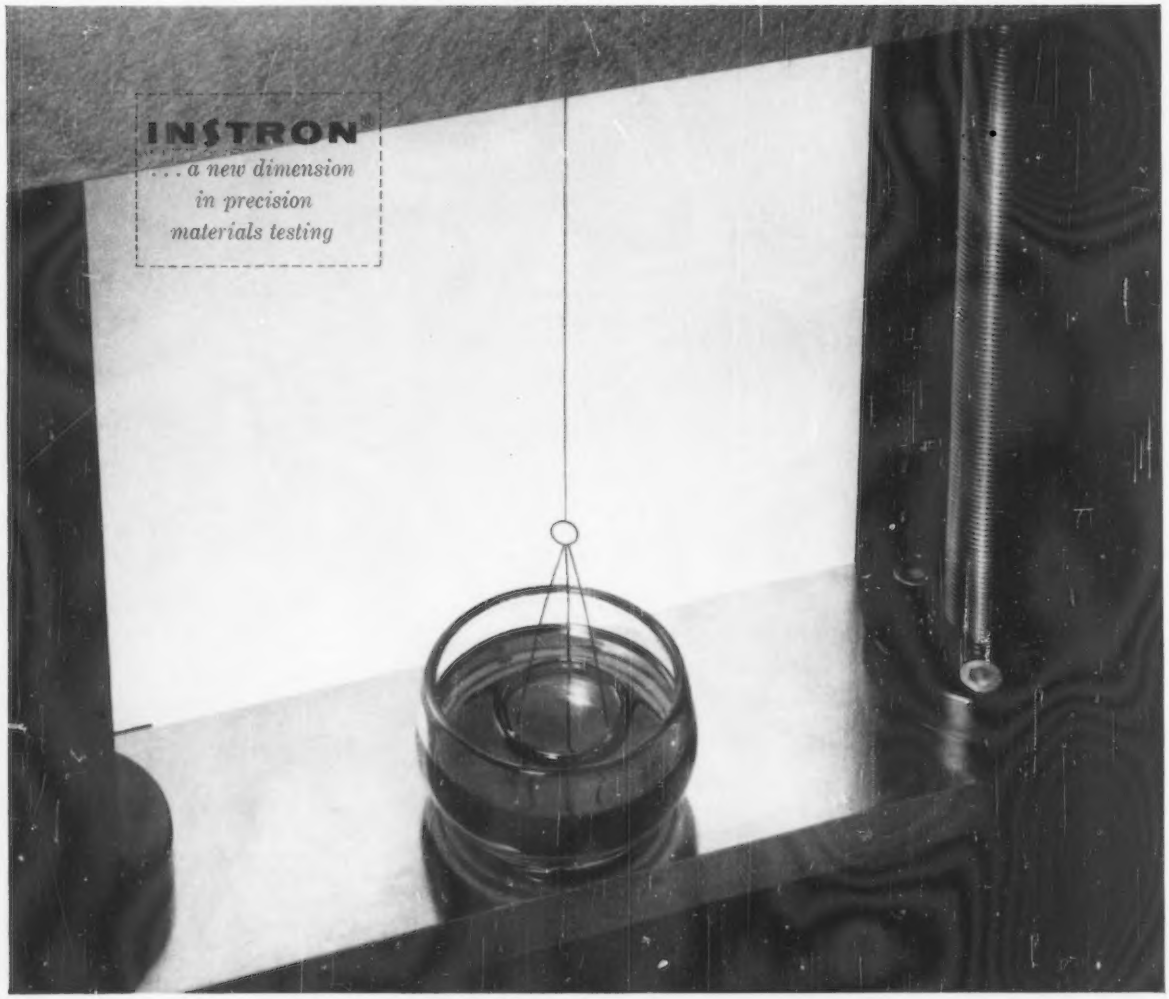

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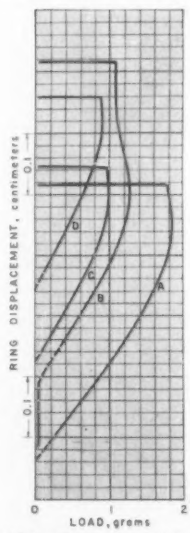

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ASTM BULLETIN

February 1960 **Number 244**

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17,000 copies of this issue printed

ASTM Bulletin is indexed regularly by Engineering Index Inc.
ASTM Bulletin is available on microfilm from University Microfilms, Ann Arbor, Mich.

The Society is not responsible, as a body, for the statements and opinions advanced in this publication.

ASTM Bulletin, published eight times a year, January, February, April, May, July, September, October, and December, by the American Society for Testing Materials. Publication Office—20th and Northampton Sts., Easton, Pa. Editorial and advertising offices at the Headquarters of the Society, 1916 Race St., Philadelphia 3, Pa. Subscriptions, United States and possessions, one year, $3.50, two years $6.00, three years, $8.50; Canada, one year, $4.00, two years, $7.00, three years, $10.00. Other countries, one year, $4.50, two years, $8.00, three years $11.50. Single Copies—75 cents. Second-class mail privileges authorized at Easton, Pa.

This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.123.

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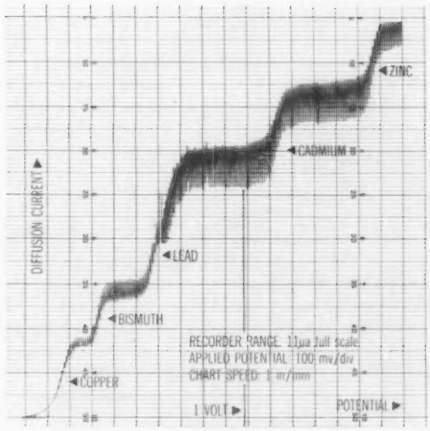

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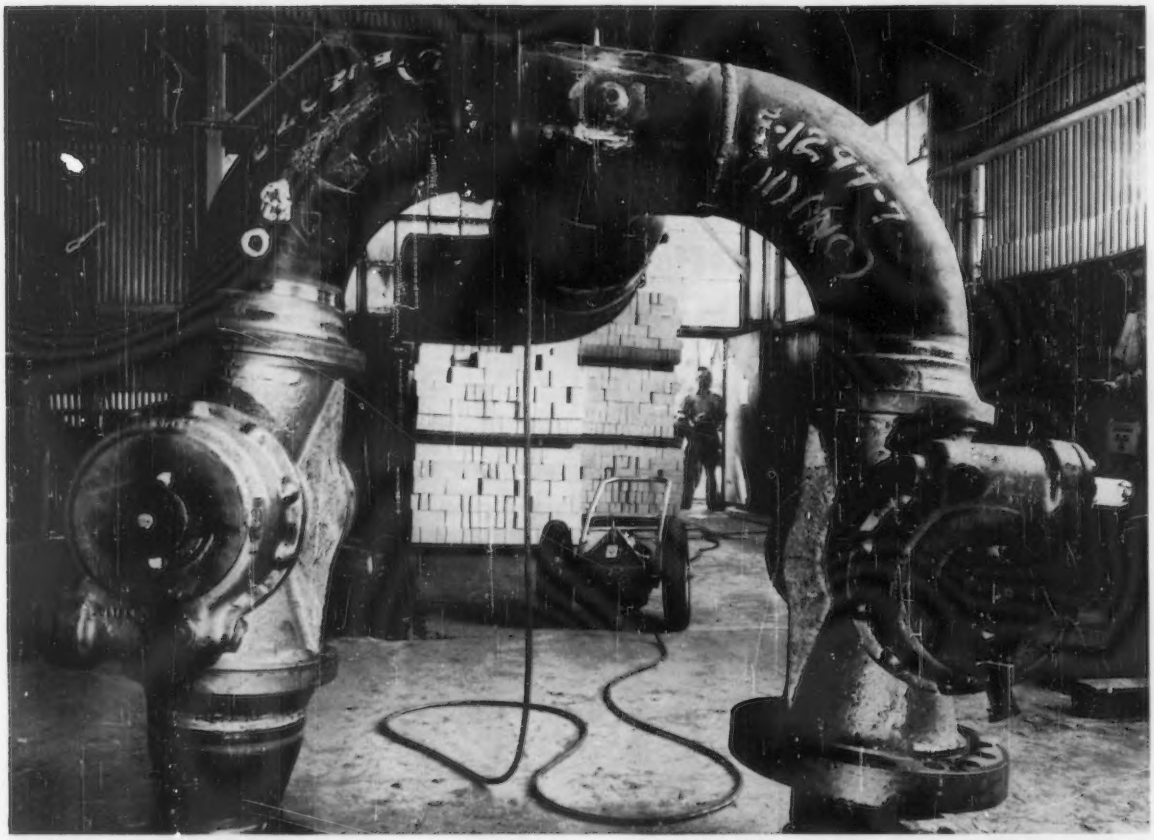

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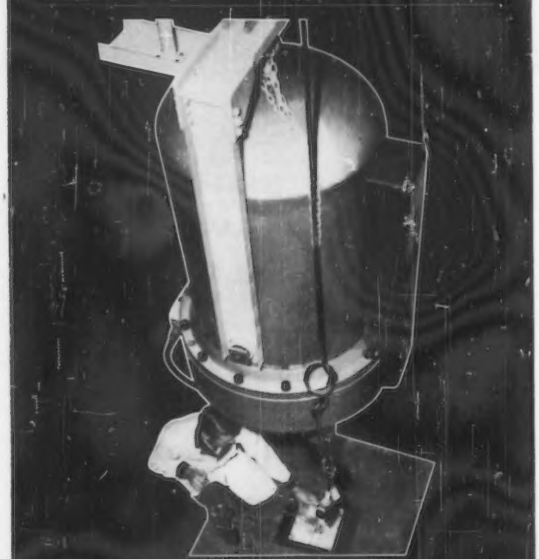
JR	1	8	1
AR	2	75	1



Model JR, 1 Mev Van de Graaff x-ray generator used for inspection of fuel elements. Courtesy Babcock & Wilcox Co.

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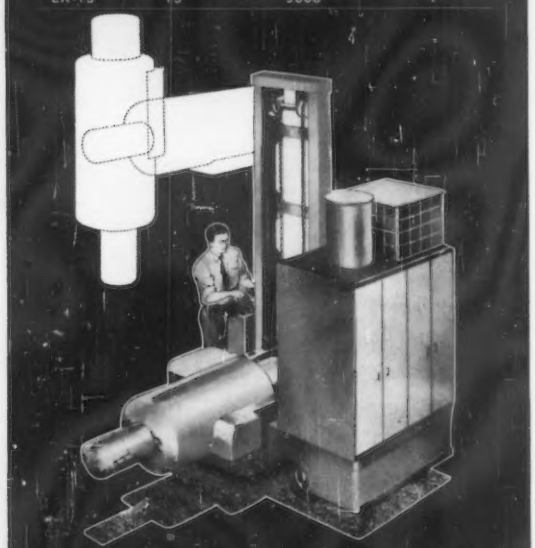
LR-12	12	2300-18000	1-8
LR-15*	15	3000	1



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ASTM BULLETIN

Research and Standards for Materials

Number 244 February 1960

63rd Annual Meeting Atlantic City, N. J., June 26—July 1

THE 63RD ANNUAL Meeting of the Society will be held in Atlantic City, N. J., at the Chalfonte-Haddon Hall the week of June 26 to July 1. Complete details of this meeting will appear with the Provisional Program in the April issue of the ASTM BULLETIN. Outlined on these pages are some of the highlights of the technical and special events of the week including titles and authors of the papers in the various symposia.

The following sessions and symposia will be held:

Sessions

- Fatigue
- Steel
- Non-Ferrous Metals
- High Temperature
- General Testing
- Concrete
- Road and Paving Materials
- Soils
- Low-Temperature Properties of High-Strength Materials

Symposia

- Sonic Fatigue
- Nuclear Methods in Soils
- Shear and Torsion Testing
- Metallographic Specimen Preparation
- Radiation Effects and Dosimetry
- Progress in Materials Sciences
- Nature and Origin of Strength of Materials
- Quality of Observations

Materials Science . . .

Solid-State, Surface Chemistry, Ductile Ceramics in Division Program

RECENT PROGRESS in materials science and nature and origin of strength of materials are the subjects of two 1960 Annual Meeting symposia sparked by the Society's precocious infant—the Division of Materials Sciences. This venture into the fundamentals, while not the Society's first, is probably its most ambitious—a single program comprising eight papers by leading scientists.

Leading off in the first session on recent progress in materials science will be Harvard's Dean Harvey Brooks, who will discuss the accomplishments and limitations of solid-state theory. Contributions of surface chemistry and physics will be covered by Prof. M. J. Sinnot of University of Michigan; University of Pennsylvania's Prof. J. N. Hobstetter will discuss the relationship between mechanical and electrical properties of semiconductors; and Prof. Earl R. Parker of University of California will tell about the exciting new field of ductile ceramics.

The division, recognizing that the science of today is the engineer's bread and butter of tomorrow, in these two symposia and more to follow, aims to hasten the process whereby new knowledge is turned into products recovering many times over the dollars spent in basic research.

The program for the second symposium, on nature and origin of strength of materials, will be announced in the April ASTM BULLETIN—watch for it. It will also feature well-known authorities and will bring you up to date in this rapidly developing area.

These two symposia will establish the complexion of the new division and should serve to indicate that there will be no competition with the ASTM technical committees.

Cooperation in "Acta Metallurgica"

On invitation of the sponsors—ASM and AIME—ASTM will become a cooperating society with The American Institute of Physics and about 20 other societies to aid in publication and distribution of *Acta Metallurgica*, an international fundamental journal in the metals field. This action, the result of a recommendation of the division's steering group to the ASTM Directors, is in keeping with the intention that the division cooperate with other societies in its operations.

To have the Society as a cooperating organization in the publication of *Acta Metallurgica* is of particular interest to our members since it will make a special subscription rate of $15 available rather than the regular rate of $25.

The steering committee of the division, under the chairmanship of past-president K. B. Woods, hopes to complete a scope and organizational framework for the division by the time of the 63rd Annual Meeting. The Long-Range Planning Committee of the Society is studying the matter of where the division fits into the ASTM organizational framework and may recommend changes in the By-laws to accommodate the new division.

63rd Annual Meeting

Symposium on Nuclear Methods for Measuring Soil Density and Moisture

Sponsored by Committee D-18 on Soils for Engineering Purposes

Application of Nuclear Soil Meters to Compaction Control for Airfield Pavement Construction—P. F. Carlton, Corps of Engineers, U. S. Army.

The Use of Nuclear Test Methods in Civil Engineering—T. W. Van Zelst, Soiltest, Inc.

Experiences with Nuclear Moisture and Density Probes on O'Hare Field Project, Chicago, Ill.—J. P. Gnaedinger, Soil Testing Services, Inc.

Design and Calibration of a Neutron Moisture Meter—K. N. Burn, National Research Council of Canada.

Nuclear Methods for Determining Density and Moisture of Soils—O. K. Neville, Nuclear-Chicago Corp.

Use and Reliability of Radiation Methods in Soil Measurements—H. Gray, Ohio State Univ.

Comparison of Nuclear and Sand Cone Methods of Density and Moisture Determinations for Four New York State Soils—Sidney Mintzer, New York Department of Public Works.

Symposium on Shear and Torsion Testing

Sponsored by Subcommittee XXV on Shear and Torsion Tests of Committee E-1 on Methods of Testing

Session 1—Shear Testing

Maximum Shear Strain Measurements and True Yield Point Determination by the Use of the Photoelastic Coating Technique—F. Zandman, Tatnall Measuring Systems Co.

The Design and Development of a Tensile Loaded Shear Specimen—E. J. Zapel, Boeing Airplane Co.

Stress Distribution in Shear-Sheet Specimens—C. S. Yen, Douglas Aircraft Co.

Interpretation of Plastic Deformation in Tested Specimens in Light of Mechanics of Dissipative Systems—C. Riparbelli, Convair Division of General Dynamics Corp.

Prepared Discussion on Photoelastic Analysis of Sheet Shear Specimens—William Bradley, Michigan State Univ.

Session 2—Shear Testing

Method of Determining Shear Yield Strength—J. Boysen, Boeing Airplane Co.

Evaluation of Test Variables in Shear Testing of Titanium Alloys—H. Scott Bandy, Lockheed Aircraft Corp.

Bonded Metal-to-Metal Shear Testing—L. R. Lunsford, Convair Division of General Dynamics Corp.

Shear Testing Spot-Welded Steel—A staff member, The Budd Co.

Prepared Discussion on Methods of Shear Testing—R. F. Klinger, Wright Air Development Center

Session 3—Torsion Testing

Shear and Torsion Tests Used at U. S. Forest Products Laboratory for Wood, Plywood, and Sandwich Constructions—W. G. Youngquist and E. W. Kuenzi, U. S. Forest Products Laboratory.

Techniques for Torsion Testing of Refractory Materials at Temperatures up to 2800 C—C. E. Waller and M. L. Stehsel, Aerojet-General Corp.

The Study of High Polymers by Means of the Torsion Pendulum—N. G. McCrum, E. I. du Pont de Nemours and Co., Inc.

Symposium on Present Methods of Metallographic Specimen Preparation

Sponsored by Committee E-4 on Metallography

Introduction—*The Development of Polishing*—Mary Norton, Watertown Arsenal

Polishing for Retention of Inclusions—C. F. Brandenburg, General Motors Corp.

Chemical and Electrochemical Polishing of Metallographic Specimens—F. M. Cain, Jr., Nuclear Materials and Equipment Co.

Mechanical Polishing—H. S. Link, U. S. Steel Corp.

The Use of Vibratory Polishing for Metallographic Sample Preparation—G. R. Grieger, Jones & Laughlin Steel Corp.

Application of Vibratory Polishing in Hot Cell Metallography—E. L. Long, Jr., and R. J. Gray, Union Carbide Nuclear Co.

Automatic Polishing Methods for the Preparation of Metallographic Specimens—R. L. Anderson

Diamond and Hard Abrasive Polishing—E. C. Olden, Frankford Arsenal

Symposium on Radiation Effects and Radiation Dosimetry

Sponsored by Committee E-10 on Radioisotopes and Radiation Effects

Radiation Testing of Enrico Fermi Reactor Prototype Fuel Pins—P. R. Huebotter, A. A. Shoudy, and M. A. Silliman, Atomic Power Development Assoc., Inc.

Comparison of Mass Spectrometry Methods with Radiometric Methods Used in Determining Fuel Burn-up—J. E. Hudgons, Westinghouse Electric Corp.

High Intensity Gamma Ray Dosimetry—R. E. Brocklehurst, Wright Air Development Center.

Comparison of Threshold Detector and Calorimetric Measurement of the Energy Absorbed by Hydrogen in a Reactor—Daniel Binder, G. D. Bopp, and R. L. Towns, Oak Ridge National Laboratory.

Dosimetry of Mixed Radiations by Luminescence Degradation—F. H. Attix, U. S. Naval Research Laboratory.

Neutron Spectrum Determinations at Low-Flux Levels—Paul Kruger, Nuclear Science and Engineering Corp.

Reactor Spectra Considerations in Radiation Effects Predictions—John Romanko, Convair Division of General Dynamics Corp.

An Analysis of Determinant Factors in Radiation Effects Testing of High Polymers—E. G. Fritz, Convair Division of General Dynamics Corp.

The Importance of Simple Geometry in Energy Absorption Calculations—R. L. Johnston, Convair Division of General Dynamics Corp.

Symposia on Recent Progress in Materials Sciences, and Nature and Origin of Strength of Materials.

These two symposia are being sponsored by the new Division of Materials Sciences. The April issue of the ASTM BULLETIN will contain detailed plans for these two symposia. The program as developed to date appears on page 5 of this BULLETIN.

Symposium on Quality of Observations

Sponsored by Committee E-11 on Quality Control.

Definition of Precision and Accuracy—R. B. Murphy, Bell Telephone Laboratories, Inc.

How to Evaluate Precision—W. S. Connor, Research Triangle Inst.

How to Evaluate Accuracy—W. J. Youden, National Bureau of Standards

Outliers or Suspect Observations—Milton Perry, Bell Telephone Laboratories, Inc.

Marburg, Gillett Lectures

The Marburg Lecture will be delivered by Farrington Daniels, Professor of Chemistry at the University of Wisconsin. Professor Daniels' topic will be solar energy.

R. C. Dalzell, Chief of the Engineering Development Branch of the Division of Reactor Development, Atomic Energy Commission, will deliver the Gillett Memorial Lecture on the subject of atomic and nuclear reactor fuel elements.

Apparatus Exhibit

As the copy for this article goes to the printer, 41 exhibitors have contracted for space in the biennial ASTM apparatus exhibit, an important feature of the Annual Meeting. At booths in the Vernon Room and the English Lounge of Haddon Hall, manufacturers and distributors will display late models of a wide variety of testing apparatus and laboratory supplies for many types of ASTM activity.

Photographic Exhibit

The biennial technical photographic exhibit will be on display adjacent to the apparatus exhibit. The best of our members' efforts in technical photography will illustrate apparatus, instruments, processing and testing techniques, and standards. A large section will be devoted to photomicrographs and electron micrographs dealing with many kinds of materials in magnifications up to 50,000×. A special section will be devoted to student entries.

Special Events

In the April issue of the ASTM BULLETIN will be complete information on the special events at the Annual Meeting. The President's Luncheon will be held on Tuesday, June 28. The program will include the annual address by the Society's President, Frank L. LaQue, vice-president and manager, Development and Research Division, The International Nickel Co., Inc.; the presentation of awards and recognition of long-time members. Wednesday evening, June 29, the annual dinner, sponsored by the Philadelphia District, will be held. An entertainment committee headed by H. W. Stuart, vice-chairman, Philadelphia District Council, U. S. Pipe and Foundry Co., is completing its plans for the evening's program. Mr. J. J. Moran of Kimble Glass Co. is chairman of a special committee of the Philadelphia District Council organizing a week-long program of special entertainment for the ladies.

ACR Notes

Administrative Committee on Research

What Price Accurate Test Methods?

By A. T. McPHERSON[1]

IN THE preparation of a purchase or performance specification for a given product in which the limits of dimensions, composition, or other characteristics are being established, it is often found that the dispersion of the test results, attributable to errors of measurement rather than to nonuniformity of product, is a significant fraction of the stipulated tolerance. Different specification-writing committees react to this situation in different ways:

1. The tolerance may be enlarged by the amount of the uncertainty in testing, the result being the acceptance of a certain number of unsatisfactory items.

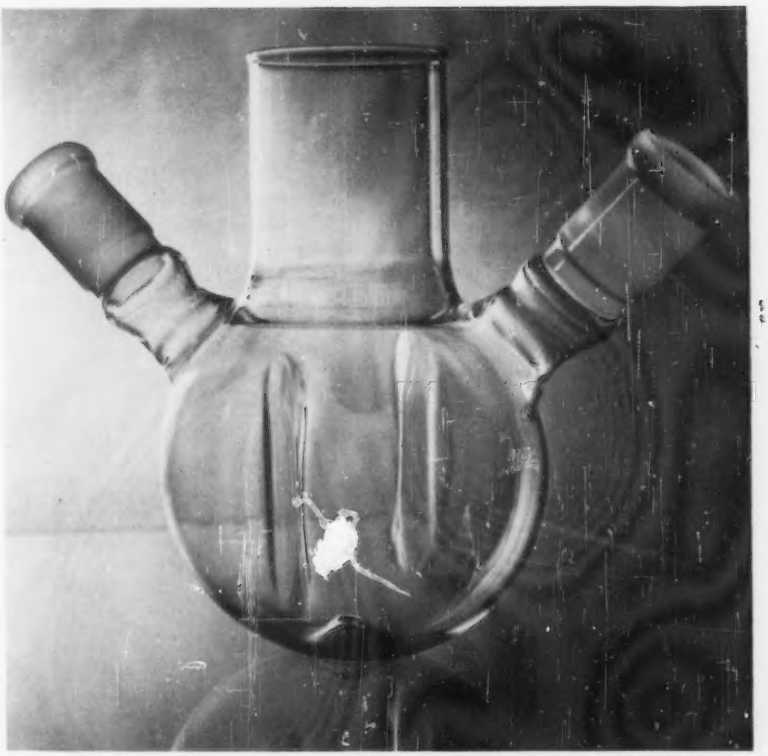
2. The tolerance may be reduced by the amount of the uncertainty in testing in order to insure that substantially all accepted items will meet the requirements. In this it is acknowledged that some satisfactory items will be rejected. (This step becomes necessary when safety is the prime factor or when an important economic loss might result from the acceptance of a single unsatisfactory product.)

3. The tolerance may be a compromise between the desires of the producer to increase, and the purchaser to decrease, the magnitude of allowable error.

When any of these three ends is reached, there is likely to have been a

(*Continued on p. 10*)

[1] Associate Director, National Bureau of Standards.



MORTON FLASK TESTS AUTOMOBILE RADIATOR METALS AT 12,000 RPM

Flask holds water and antifreeze mixture in a laboratory bench test for corrosion. A small disk of the metal on test spins at 12,000 rpm inside the flask. Grooves in the flask assure that air is well mixed into the coolant by the spinning disk. Method developed at Chrysler Corporation's Engineering Division. Eleventh ASTM Photographic Exhibit. C. Augustine and D. N. Collins, Chrysler Corp.

1959 Financial Operations Show Favorable Balance

Budget for 1960, however, indicates a deficit

As a result of 1959 financial operations, the Society was able to show a gain of budgeted operations of almost $74,000 which enabled the Society's surplus to be increased from $317,000 to $411,000. Despite this relatively favorable picture the Society is still not as healthy financially as it might be, because, as a glance at the figures shown below will indicate, our surplus is still considerably less than a half year's operations, and in many financial circles it is considered that a minimum surplus which should provide a comfortable "feeling" would be a full year's operations. In other words it should be almost three times what it is. Nevertheless the Finance Committee is pleased with the outcome of 1959 and it is hopeful that 1960 will again be a good year despite the fact that a deficit is being *budgeted*.

Total receipts were over the budget almost $100,000 but disbursements also ran over by about $55,000, showing a favorable balance of about $45,000 over the expected surplus for 1959.

In considering Society finances, it must always be kept in mind that they are influenced greatly by the appearance of the big Book of ASTM Standards which comes out every three years. Naturally when more than 60 per cent of our income is received from the sales of publications and a high percentage of this from the Book of Standards the proceeds from the distribution of a new Book markedly affect our operations.

1960 BUDGET SUMMARY

Estimated Receipts

		Per cent
Dues and Entrance Fees	$388 175	28.9
Publications	810 000	60.3
Miscellaneous	145 500	10.8
Total Current Receipts	$1 343 675	100.0

Estimated Disbursements

		Per cent
Publications	$581 500	41.1
Salaries	485 000	34.3
General Office Expenses	121 500	8.6
Technical Committee Expenses	14 500	1.0
Meetings	28 750	2.0
Headquarters Occupancy Expenses	77 500	5.5
Retirement, Insurance, Health Expense	61 000	4.3
Miscellaneous Expenses	45 250	3.2
Total Operating Disbursements	$1 415 000	100.0

It is notable that our sales of books and other publications totaled more than $1,000,000 (actual cash receipts were under this, but 1959 was the first year when we actually billed more than this amount).

It is significant that income from the dues of membership still is well under 30 per cent of our total and that the Society is able to be active in so many areas only because it can distribute its books, get the standards into use, and get the information which is so valuable in our technical publications out to industry and government where it can be used.

1959 Receipts. From the accompanying table showing the source of operating receipts, it will be noted that dues and entrance fees accounted for almost $374,000, 25.9 per cent of the total, with publication sales reaching 66.6 per cent, or about $965,000. Miscellaneous income, dividends, exhibit, advertising, was about $111,000, or 7.6 per cent.

1959 Disbursements. Biggest item in disbursements was the cost of publications, which was about $617,000. This includes the reserve for the Book of

OPERATING RECEIPTS

Source	1959		1958		1957		1956	
		Per cent		Per cent		Per cent		Per cent
Dues	$373 583	25.9	$297 802	27.5	$283 389	27.7	$268 985	25.0
Sales of Publications	964 793	66.6	657 019	60.6	623 936	61.2	695 950	64.0
Miscellaneous								
Advertising	47 572	3.3	52 512	4.8	54 326	5.3	43 324	...
Interest and Dividends	29 099	2.0	31 097	2.9	30 492	3.0	29 798	...
Registration Fees	18 490	1.3	16 495	1.5	16 404	1.6	16 622	...
Exhibit	11 840	0.8	20 245	1.9	2 950	0.3	20 168	...
Other	3 606	0.2	8 846	0.8	9 183	0.9	7 704	...
Total Miscellaneous	110 607	7.6	129 195	11.9	113 355	11.1	117 617	11.0
Total Receipts	$1 448 983	100.0	$1 084 016	100.0	$1 020 680	100.0	$1 082 552	100.0

OPERATING DISBURSEMENTS

Item	1959		1958		1957		1956	
		Per cent		Per cent		Per cent		Per cent
Publications	$616 589	44.8	$577 036	40.5	$430 175	41.9	$342 323*	38.1
Salaries	431 444	31.4	406 126	35.8	360 171	35.2	309 402	34.3
General Office Expense	125 384	9.1	104 064	9.2	93 079	9.1	111 557	12.5
Meetings and Technical District Committees	53 560	3.9	48 963	4.3	29 054	2.7	42 206	4.8
Headquarters Occupancy	55 060	4.0	40 144	3.5	41 089	4.0	35 582	4.0
Retirement, Health	62 830	4.6	48 392	4.3	49 672	4.8	32 603	3.7
Miscellaneous	30 184	2.2	27 687	2.4	24 922	2.3	22 840	2.6
Total Disbursements	$1 375 051	100.0	$1 252 412	100.0	$1 028 162	100.0	$896 513	100.0

* Does not included $85,000 earmarked as a reserve for the 1958 Book of Standards and not expended.

Standards and for the *Proceedings*. Salary expenditures were $431,000; general office expenses, including provision for depreciation and amortization of the loan on the Cherry St. Property, were about $125,000. Percentages of other costs are shown in the table.

1960 Budget. Estimated receipts, as shown from the accompanying table, run about $1,344,000 with some 60% of this coming from the distribution of publications. Obviously with so much publishing work the cost of publications is our major expenditure and it is expected to reach a figure of $581,500. Adding to this salaries, other operating expenses, health and retirement insurance, etc., we come out with total disbursements estimated at $1,415,000 which would give us a deficit of about $71,000. We may well overcome this deficit because the receipts are estimated very conservatively and disbursements rather liberally.

Income—$1,049,000
(About $100,000 over the budget and comparing with our 1956 operations of $1,083,000.)

Spent—$1,375,000
(This was $55,000 over the budget and a very large figure mostly because of our very heavy publication expenses. When it is considered that we took in more than $1,000,000 from the sale and distribution of the books it is obvious the cost will be a correspondingly large figure.)

Net—A substantial operating gain of $74,000
(This is good because this is the year in our budget when a favorable gain must help carry over the following two leaner years.)

Surplus—$411,000
(This is an improvement over the surplus at the end of the previous year of $317,000, but it is still less than it should be.)

This is the second year after the appearance of the 1958 Book of Standards and consequently we cannot expect nearly the income from the sale of this Book which we enjoyed in 1959. Nevertheless some $200,000 is expected to come from this tremendous ten-Part publication.

The budget has provision for some improvement in current buildings rather than to take all of these sums from the Building Fund. There is also provision for the Fellowship and Grants-in-Aid program totaling almost $12,000. Details of the budget are shown in the accompanying summary.

Defense Dept. Standardization Is Boon to Taxpayers

INDUSTRY STANDARDS, specifications, and practices will be adopted by the Department of Defense whenever possible, according to Perkins McGuire, Assistant Secretary of Defense for supply and logistics, who spoke at the annual meeting of the American Standards Assn. held in New York City, Dec. 9, 1959. One of the most significant achievements of the DOD cataloging program has been the complete identification and cataloging of about 3½ million different items for the military, made by more than 34,000 different companies. More than 500,000 new items enter the system every year, and an equal number are eliminated. "If you consider that we save about one million dollars a year in management expenses for every 1000 items eliminated from our supply system, you may get an idea of the attendant savings in such a standardization effort," said Mr. McGuire.

Earlier this year a study of the defense standardization effort was made by ASA on behalf of the Department of Defense in parallel with an analysis by the Department itself. Review of these studies by the DOD led to certain conclusions, some of which are: (1) the military should concentrate its standards work on high-priority items and avoid giving equal attention to inconsequential projects involving only small purchases; (2) an engineering standardization program should be actively pursued at the development and drawing board stage to preclude the need for standardization when the finished products have entered the supply system; and (3) the military should not duplicate industry standards.

PRESHADOWED CARBON REPLICA OF NEOPRENE ACCELERATOR CRYSTALS

Crystals were shadowed with Pt-Pd (3 : 1), then coated at normal incidence with carbon. Crystals were dissolved in alcohol, then replica was photographed. Magnification 16,000×, reduced one-half for publication. Eleventh ASTM Photographic Exhibit. Walter S. Kay, E. I. du Pont de Nemours & Co., Inc.

ACR Notes

(*Continued from p. 7*)

considerable expenditure of time and effort by the cognizant committee. However, the major expense arising from inaccurate test methods will occur in the use of the specification when marginal compliance of the product with the requirements is involved. Differences between the results of tests by the supplier and by the purchaser may occasion costly delays while referee tests are being run, as well as serious controversies, and even questions as to the effectiveness of the specification.

Is there a better solution? Only one: the development of more accurate methods of test—methods that will use only a small fraction of the product limits. By product limits we mean the range of dimensions, composition, or other characteristics within which the product is acceptable for the intended use.

There are several avenues to greater accuracy of testing, including the following: (1) the use of accurately calibrated standards of measurement, particularly when the product is a component of an assembly; (2) the better control of environmental conditions such as temperature and humidity; (3) the use of more sophisticated testing equipment; (4) the more exact description of testing techniques; and (5) the development of new or refined procedures. Very often the achievement of the desired accuracy may require simultaneous attention to several of these factors. In certain instances a great deal of research may be required, and the time and expense involved may be considerable.

It is seldom possible to guarantee results. Even so, there are circumstances under which the product is of such importance and the need for it so critical that almost any expenditure of time and money for greater accuracy of testing will be fully warranted. An illustration is the wartime development of test methods for synthetic rubber. Under the stress of necessity for interchangeable use of the synthetic rubbers of various producers, test methods were pushed to much higher degrees of accuracy than had been thought possible in the days of natural rubber.

Under most circumstances, however, practical realities demand that costs be considered. Even though test methods in use may be recognized as being of inadequate accuracy, it must be determined whether possible savings through more accurate methods are sufficient to warrant the expenditure of the time and money necessary to develop them. In such a determination there should be considered, on the one hand: (1) the expense of the required committee meetings; (2) the cost of planning, administering, and conducting the necessary research and development; (3) the cost of printing and promulgating the new test method; and (4) the expense of procuring the new laboratory equipment and of training the staff necessary for placing the new method in operation. To counterbalance these considerations, there are: (1) the savings to the producer through a lower rate of rejection of products; (2) the savings to the purchaser through greater assurance of quality of product; (3) the avoidance of delays occasioned by questioned or rejected shipments; (4) the savings in the costs of referee tests made necessary by disagreement between producer and purchaser when such disagreement is caused by indefinite test results, with attendant saving of demurrage on shipments and losses through delayed turnover of goods; and (5) the possible widening of the product limits set by the specification with the attendant reduction in manufacturing costs.

These factors are not of a nature that will permit easy or exact evaluation, but, with planned and careful study, it should be possible to estimate their cost. Such a study would be similar to a market survey in which both economic and technical factors are considered. It is probable that personnel skilled in market analysis would be best able to contribute to pilot projects with respect to specifications for specific products in their fields of specialization. There is, of course, expense involved in studies of this nature, but the expense

(*Continued on p. 14*)

GALILEO GALILEI (1564–1642). Born in Italy, in the same year as William Shakespeare, Galileo Galilei became professor of mathematics at the University of Pisa and later at the University of Padua. While still in his twenties, he presented for the first time the views now held on the dynamics of a particle. One of his great contributions was in subjecting principles of mechanics to experimental test. His *Discourse on Two New Sciences* contains the first analysis of beam action.

"Long experience has taught me this about the status of mankind with regard to matters requiring thought: the less people know and understand about them, the more positively they attempt to argue concerning them, while on the other hand to know and understand a multitude of things renders men cautious in passing judgment upon anything new."

The Assayer

This is one of a series of photographs from a collection compiled by Prof. Jasper O. Draffin and displayed in the Arthur N. Talbot Laboratory, University of Illinois.

NEW ASTM PUBLICATIONS

Electron Microscope Uses Extended

TECHNIQUES TO study the morphology of phases in high-temperature alloys, structure and growth of tin oxide, metallography of neutron-irradiated steels, and dislocations in thin stainless steels are among the eleven topics covered in this new Symposium on Electron Metallography.

The electron microscope is not a new analytical tool. In metallography, however, as in most areas of science, established instruments find continued new uses through improvement of techniques and modifications of the basic instrument. In this symposium the metallurgist will find described a variety of promising techniques. It is from such sparks of ingenuity that new standardized techniques can be evolved. The contents include:

Introduction—N. A. Nielsen
Electron Microstructure of Precipitation-Hardenable Austenitic and Nickel-Base Alloys—Sixth Progress Report of Subcommittee XI on Electron Microstructure of Metals
Morphology of Phases in High-Temperature Alloys as Revealed by the Electron Microscope—J. R. Mihalisin
Simplified Electron Metallography of Steels—G. E. Pellissier
Techniques for Studying Structure and Growth of Tin Oxide by Electron Microscopy—P. S. Trozzo
Electron Metallography of Neutron-Irradiated Steels—R. F. McCartney and P. S. Trozzo
Electron Microscopy of Tin Plate—P. A. Stoll
Instrument Modification for Routine Electron Diffractom try—G. R. Grieger
Structure Analysis with Routine Electron Diffraction—G. R. Grieger
A Simple Application of the Carbon Replica Technique—L. Pellier
Electron Microscope Observations of Dislocations in Thin Metal Foils—R. M. Fisher and A. Szirmae
Microstructure of a Cast Age-Hardenable Nickel-Chromium Alloy—R. F. Decker and C. G. Bieber

STP 262, 134 pages, hard cover, price $4.25, to members $3.40.

Manual on Industrial Water and Waste Water

THE INFLUENCE of water on various industries ranges from that in paper manufacture, where enormous volumes are used and its quality is of great importance, to that in small industries where only incidental supplies are needed. At no level, however, can the amount and nature of the available water be disregarded lest a plague of supply failure, contamination, corrosion, scaling, or other difficulty arise to interfere with the manufacturer's operations and to sap his profits.

Executives, plant managers, designers, technologists, and administrators will find in this manual information on the influence of water on industries in which it is used either as a raw material or in conjunction with manufacturing processes. Combined with general discussion of the problems arising from industrial use of water are details of specific control procedures and instructions for such critical operations as sampling water under the various conditions and in the several forms in which it is employed.

Chemists and other technologists having special knowledge of water can use the manual as a reference for specific information unassembled elsewhere. Standard methods for sampling, analysis, reporting, and testing water, developed by ASTM Committee D-19 on Industrial Water, are included for ready reference, together with constants, names, and other factors of immediate usefulness to water practitioners. Techniques which have not yet been standardized are discussed to aid the water specialist in keeping abreast of new developments.

This edition of the manual represents a substantial expansion of the first edition. It has been designed to satisfy the growing need for dependable information about water and the problems its use entails.

STP 148-D, 660 pages, hard cover, price $11.00, to members $8.80.

Editorial Change in Method D 1322 (Smoke Point of Jet Fuels)

One section of the Tentative Method of Test for Smoke Point of Jet Fuels (D 1322 – 58 T) has been changed editorially. This method appears on page 773 of the 1958 Book of ASTM Standards, Part 7, and on the same page of the 1958 Compilation of ASTM Standards on Petroleum Products and Lubricants. Section 9(*b*) has been changed to read: "Report the average corrected by the use of the correction factor as the smoke point of the sample, without any unit designation."

Electrical Insulating Liquids

Compilation of Standards, D-27

RAPID DEVELOPMENTS in liquid insulation make this book a welcome reference for those concerned with problems associated with high-voltage power transmission.

For the first time, ASTM now publishes its standards for liquid electrical insulating materials in a separate volume containing only standards in this field. Engineers and scientists concerned with this area of technology will find the 48 standards in this compilation to be a valuable addition to their reference libraries.

Typical standards included are: Test for Cloud and Pour Points; Tests for Interfacial Tension of Oil Against Water; Tests for Corrosive Sulfur in Electrical Insulating Oils; Test for Scavenger Content in Askarels; and Recommended Practice for Safe Use of Oxygen Combustion Bombs.

ASTM Standards on Electrical Insulating Liquids and Gases, 336 pages, hard cover, price $4.25, to members $3.40.

Up-to-date Light Metal Standards Available

Compilation of Standards, B-7

WITH THE publication of the 1959 edition of the Compilation of ASTM Standards on Light Metals and Alloys, metallurgists and engineers will have available the latest materials standards in this area of technology. The book contains 57 standards, 33 of which are revised or changed in status since the previous edition. In addition it contains 3 new standards including one for aluminum-alloy pipe for gas and oil transmission. A new specification for aluminum-coated steel wire for electrical transmission purposes and a new method of test for electrical conductivity using eddy current procedures are also included.

In all, the book contains 3 recommended practices, 10 methods of test, and 44 specifications covering such materials as aluminum and aluminum-alloy ingots, castings, bars, rods, wire, shapes, forgings, pipe, tubes, sheet, plate, filler metal, and wrought products for electrical purposes. Magnesium and magnesium-alloy ingots, castings, tubes, sheet, forgings, bars, rods, and shapes are also covered. In addition to general methods of test, there is also a standard for electroplating on aluminum alloys.

ASTM Standards on Light Metals and Alloys, 368 pages, hard cover, price $4.50, to members $3.60.

New and Revised Methods for Chemical Analysis of Metals Now Available as Reprints

STANDARDS RELATING to the chemical analysis of metals and to emission spectroscopy that were issued or revised in 1959, but which do not appear in any of the Parts of the Book of Standards, are now available as separate reprints. The one new standard is the Methods for Chemical Analysis of Zirconium and Zirconium-Base Alloys (E 146). The six revised standards are:

Method for Spectrochemical Analysis of Zinc-Base Alloys and High-Grade Zinc by the Solution–D-C Arc Technique (E 27)

Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron (E 30)

Method for Spectrochemical Analysis of Tin Alloys for Minor Constituents and Impurities (E 51)

Rec. Practices for Photographic Processing in Spectrochemical Analysis (E 115)

Rec. Practices for Photographic Photometry in Spectrochemical Analysis (E 116)

Method for Spectrochemical Analysis of Pig Lead by the Point-to-Plane Spark Technique (E 117)

Engineering Education

DEVELOPMENTS IN technology are occuring at a rate unmatched in the history of the world. Each of the basic sciences is expanding into the unknown at a faster and faster rate. This is true for mathematics, chemistry, physics, and for all of the biological sciences. These developments provide new tools to work with in such fields as agriculture, engineering, medicine and many others. Corresponding changes are taking place in communications, transportation, and in such areas as rockets and missiles.

All of this is common knowledge. What is not so well known—and, in fact, not even well understood—is the impact of these great achievements and advancements of science on education, not only on college and university curricula, but also on high schools, elementary schools, and the technical institutes.

It is the purpose of this symposium to present the views of educators, engineers, and industrialists on the impact of our changing environment on the field of engineering materials education. The symposium is sponsored jointly by ASTM and The American Society for Engineering Education.

Papers included are:

Introduction—K. B. Woods

ASTM Views on Engineering Education—F. L. LaQue

Education in Materials from an Educator's Viewpoint—W. T. Alexander

Industry's Viewpoint on Education in Materials—Melvin F. Wood

Education in Engineering: A Perspective—Eric A. Walker

Nature and Properties of Materials—A Discussion of the Report of ASEE Follow-up Subcommittee on Materials—Glenn Murphy

Further Challenges of the Design Engineer to the Metals Engineer and Their Bearing on the Metals Engineer's Education—Glenn B. Warren

Viewpoint of the Civil Engineer—Henry A. Lepper, Jr.

STP 263, 60 pages, heavy paper cover, price $2.00, to ASTM and ASEE members $1.60.

New Reference Radiographs of Light-Metal Castings Will Aid Aerospace Industry

AIRCRAFT AND missile manufacturers have a new tool for inspecting and maintaining the quality of aluminum and magnesium castings. Developed through the cooperation of the Quality Control Committee and the Aerospace Research and Testing Committee of the Aerospace Industries Assn., this new series comprises actual radiographs, rather than photographic reproductions. This will provide a more accurate comparison standard that will be easier to interpret.

The new series includes 25 radiographs: 13 for aluminum alloy and 12 for magnesium alloy castings. They illustrate gas holes, segregation, microshrinkage (both sponge and feather), and foreign matter in castings $\frac{1}{4}$- and $\frac{3}{4}$-in. thick. Eight grades of severity for each discontinuity are illustrated. The radiographs are designated by number according to ASTM Standard E 52, Industrial Radiographic Terminology for Use in Radiographic Inspection of Castings and Weldments. Each radiograph is mounted in an $8\frac{1}{2}$ by 11-in. cardboard frame; the 25 frames are bound in a ring binder.

While these new radiographs were developed specifically for use in the aerospace industry, all others concerned with the manufacture of light-metal castings will find them to be valuable references against which quality-control radiographs can be checked.

Tentative Reference Radiographs for Inspection of Aluminum and Magnesium Castings, ASTM Designation: E 155. Complete set $125.00.

Schedule of ASTM Meetings

This gives the lastest information available at ASTM Headquarters. Direct mail notices of all district and committee meetings customarily distributed by the officers of the respective groups should be the final source of information on dates and location of meetings. This schedule does not attempt to list all meetings of smaller sections and subgroups.

Date	Group	Place
March 1	Committee E-13 on Absorption Spectroscopy	Pittsburgh, Pa. (Penn-Sheraton Hotel)
March 1–4	Committee D-13 on Textile Materials	New York, N. Y. (Sheraton-McAlpin Hotel)
March 3	Committee E-2 on Emission Spectroscopy	Pittsburgh, Pa. (Penn-Sheraton Hotel)
March 7–10	Committee D-20 on Plastics	Cincinnati, Ohio (Netherland-Hilton Hotel)
March 9–11	Committee D-9 on Electrical Insulating Materials	Cincinnati, Ohio (Netherland-Hilton Hotel)
March 9	Ohio Valley District	Cincinnati, Ohio (Netherland-Hilton Hotel)
March 9–11	Committee C-16 on Thermal Insulating Materials	Charleston, S. C. (Fort Sumter Hotel)
March 14–15	Committee D-12 on Soaps and Other Detergents	New York, N. Y. (Park-Sheraton Hotel)
March 31–April 1	Committee D-14 on Adhesives	Philadelphia, Pa. (Sheraton Hotel)
April 4–5	Committee D-10 on Shipping Containers	Atlantic City, N. J.
April 4–5	Committee D-15 on Engine Antifreezes	Washington, D. C. (Shoreham Hotel)
April 6–7	Committee F-2 on Flexible Barrier Materials	Atlantic City, N. J.
April 19	Western New York District	Buffalo, N. Y.
April 26	Detroit District	Detroit, Mich.
May 5	Committee E-11 on Quality Control	Philadelphia, Pa. (Society Headquarters)
May 6	New England District	Place to be determined
June 16–17	Committee F-1 on Materials for Electron Tubes and Semiconductor Devices	Boston, Mass. (Statler Hotel)
June 26–July 1	**Annual Meeting**	**Atlantic City, N. J. (Chalfonte-Haddon Hall)**

ASTM Bulletin

No. 244 February 1960

Nineteen-Sixteen
Race Street
Philadelphia 3, Pa.

A New Name for ASTM?

Editor's Note.—The primary purpose of this article is to stimulate thought and response on the part of our members. Your officers urgently desire an expression of your feelings on this matter, whether pro or con. Please write to Headquarters and let us know your thoughts.

DISCUSSION CONTINUES as to the desirability of changing the name of the ASTM. As might be expected, attitudes toward this range from violently opposed to enthusiastically in favor, with a large intermediate group exhibiting varying degrees of passivity.

Those in favor dwell most frequently on the necessity of having a name that more clearly indicates the complete scope of ASTM interests. This is becoming increasingly desirable as a means of forestalling the creation of new technical organizations in the materials field or the encroachment of existing organizations by expansion into areas of activity in which ASTM should maintain its pre-eminent position to the advantage of all concerned.

Even many who should be better informed tend to think of ASTM as being concerned only with standards and testing. Without detracting in the least from the importance of these ASTM areas of activity, it seems to be necessary to emphasize as well the important and extensive work of ASTM in the broad field of materials, and particularly in its research and development programs upon which new and improved standards and testing methods are based. This does not require any de-emphasizing of ASTM's major interest in, and responsibility for, materials and testing standards. It merely makes it clearer that the ASTM is as much concerned with the development of the basis of its standards as with the standards themselves.

There is at least one point of unanimous agreement. This is that whatever name is used for the Society, the initials ASTM, by which it is most generally known and almost invariably referred to, be preserved. As in the case of the continued use of the initials AIME to describe the American Institute of Mining, Metallurgical and Petroleum Engineers, it is not essential that words be chosen that start with the letters A, S, T, and M. However, this would be desirable and might be achieved, for example, in names previously presented for discussion: Association for Standards and Technology of Materials or American Society for Standards and Technology of Materials. Another name that has been suggested is American Society for Testing and Materials. While this does not go as far as some would like toward emphasizing our concern with materials *per se*, it is a move in that direction.

Substitution of the word "Association" for "American" has raised some objections related to a suggested lack of patriotism, or even pride, in our country. On the other hand, some have praised such a change with reference to the international scope of many ASTM activities, including memberships abroad, the desirability of having ASTM standards and practices adopted in other countries, and the fact that the United States is not uniquely American among the nations comprising North and South America.

Elimination of the word "testing" has been criticized severely. These objectors point out quite properly that, in its broad sense, the word "testing" encompasses most of the activities that any new name might similarly attempt to describe. One definition of research describes it as the testing of previously conceived conclusions in the light of new facts. ASTM standards certainly require that materials be put to the test to establish that the requirements of the standards are met. It is true, also, that testing is an essential part of any research program aimed at improved materials or a more complete understanding of the properties of both old and new products. So, it is not lack of adequacy upon which giving up the word "testing" could be based. It is simply that too many people do not think of testing in the broad sense just described. They have a much narrower concept visualizing testing as the more or less routine execution of a test in accordance with a specified procedure and requiring principally manipulative skill and care rather than the special knowledge and creative thinking characteristic of most of the professional membership of our Society. Thus, there is the danger that the word "testing" in the Society's name tends to downgrade both the nature of the Society's interests and the professional stature of its members.

Some eyebrows have been raised about the proposal to include the word "technology" in a new name. Here again, the basis of objection is a fear of downgrading illustrated by a comparison of a technician with an engineer. In rebuttal, it can be pointed out that many of our most respected engineering colleges are known officially as Institutes of Technology. Their graduates do not seem to suffer any loss of prestige by graduating from an institution with the word "technology" in its name. They might reasonably be expected to be equally comfortable in a technical society with the same appellation. Graduates from other institutions might similarly extend their tolerance of graduates of Institutes of Technology to include a common membership in an Association for Standards and Technology of Materials.

On the positive side, the Greek root of the word technology means "scientific treatment" and one definition is "the scientific study of the practical or industrial arts," in this case as applied to materials and their development. These considerations would support a substitution of "technology" for "testing" where the letter "t" appears in the ASTM initials. It has none of the limitations of the word "testing" in its narrowest sense and quite reasonably indicates the scope of the Society's activities which support its prime function of creating materials standards.

It is hoped that a large number of members of the Society will give the Board of Directors and the Long-Range Planning Committee the benefit of their views on the proposed change in name. This could extend to suggestions for a better name. Perhaps it will be possible to publish typical letters or excerpts from them in future issues of the ASTM BULLETIN. Such communications should be addressed to the Editor, who will see that they come to the attention of the officers of your Society.

F. L. LAQUE

R. J. Painter Given Sick Leave

MR. F. L. LAQUE, President of ASTM, made the following announcement after a meeting of the ASTM Board of Directors in Philadelphia on Jan. 19, 1960:

In July, 1959, our Executive Secretary, Mr. Robert J. Painter, underwent an operation to eliminate a difficulty with one of his legs. His condition has been reported from time to time in the ASTM BULLETIN. Progress from this operation has been delayed. Though an ultimately favorable result is anticipated, this will require some additional time.

By action of the Board of Directors following full discussion and agreement with Mr. Painter, he has been given sick leave until June 30, 1960.

This action has been taken for two principal reasons. The first is to relieve Mr. Painter of responsibility for the day-to-day operations of the Society and thereby eliminate any strain incident to such activities and thus accelerate his recovery. The second reason is to insure the most expeditious and orderly handling of matters on which the several members of the Staff are regularly engaged and to establish a recognized authority in the Headquarters office from whom members of the Staff can secure prompt decisions.

In his capacity as Associate Executive Secretary, Mr. Raymond E. Hess has been charged with the duties and responsibilities of the office of Executive Secretary.

To the extent that his condition will permit, Mr. Painter will be available for consultation on matters that may be brought to his attention by the officers of the Society from time to time. In addition, he will continue to give special attention to matters concerned with Long Range Planning.

The action described here has been adopted as a result of discussions among Mr. Painter, Mr. Hess, and members of the Executive Committee of the Board and has been endorsed without reservation by all concerned.

ASTM Members Invited to View Construction Industry Outlook

OPPORTUNITIES for the construction industry in the 1960's will be explored at a National Construction Industry Conference to be held in the Hall of Flags of the National Chamber of Commerce Building, Washington, D. C., March 10 and 11, 1960. The conference will assess the problems of the decade ahead and will discuss ways in which the industry can progress to the benefit of the public and the construction industry. The Chamber of Commerce has invited the members of ASTM to attend.

First ASTM Grants Made Under New Fellowship Program

The first ASTM free-grant doctoral fellowship for the promotion of the knowledge of materials has been given to the University of Illinois. The $6500 grant includes $1500 for the university and $5000 for a student beginning his last year of graduate work leading to a doctor's degree related to the knowledge of materials. The student will be selected by the university, and the fellowship will be administered according to the university's rules and regulations governing fellowships.

Grants-in-aid of $1000 each also have been given to California Institute of Technology, Cornell University, University of Minnesota, Northwestern University, and The Rice Institute. These sums are to be used for promoting the knowledge of materials. At the discretion of the recipient institutions, the grants may be given to graduate students or may be applied toward the purchase of equipment to assist in furthering specific studies in the field of materials for which funds might not otherwise be available.

The fellowship and grants-in-aid program was established by the Society's Board of Directors to further the work of ASTM in the field of research and standardization for materials. The program is to continue for five years with awards being made to different schools each year.

MATERIAL QUESTIONS

NEARLY EVERY day the mail at ASTM Headquarters includes some questions about materials, specifications, test methods, or related problems. We feel that the answers, many of which are based on information given us by officers of committees in their capacity as committee officers, are of general interest. For the most part, inquiries we receive relate to the activities of the Society, either standards, research work, or publications. Often, an inquiry is such that the services of a consultant or independent testing or research laboratory is obviously required; in this event we do not hesitate to so recommend.

Phosphorus in Cast Iron

In our gray iron foundry department, working for the automotive industry, we are sometimes asked to meet ASTM Specification A-159 for automotive gray iron castings. In this connection we are aware of the standard trend toward lower phosphorus content, especially for parts designed to hold higher pressure (cylinders, brake pedals, and the like). Since this trend seems to be based on more recent developments, unknown in earlier European practice, I would be only too grateful if you would be good enough to name a few recent publications dealing with this problem.

● It has been common practice for many years in the American automotive industry to use low-phosphorus cast iron. In the early days of the industry, cast iron of medium phosphorus content, in the range of 0.35 to 0.40 per cent, was used in cylinder blocks and similar castings and it was felt this phosphorus content contributed to fluidity. However, a great deal of difficulty with internal porosity in oil lines and isolated heavy sections was common. During the 1920's it was found that lowering the phosphorus content to not over 0.20 per cent tends to eliminate porosity in castings. In the early 1930's most of the automobile companies adopted specifications for automotive castings calling for a maximum phosphorus content of 0.20 per cent. Since that time this trend has continued, and during the past ten years several of the automobile companies have been making cylinder block castings to internal specifications called for a maximum phosphorus level of 0.10 per cent.

These lower phosphorus cast irons have definitely helped to eliminate shrinkage defects and internal porosity. Use of low phosphorus, of course, also eliminates Steadite in the microstructure. This iron phosphide eutectic forms a hard abrasive segregate and its elimination improves the machining characteristics of the iron.

As far as is known the European industry has not gone to low-phosphorus irons to the same extent as the United States. This is probably partially due to the fact that the automobile industry is centered in the Great Lake Region, and the suppliers of pig iron have largely used Lake Superior iron ores, which are low in phosphorus. It is very likely that the easy availability of pig iron of low phosphorus content has helped promote this trend.

ACR Notes

(*Continued from p. 10*)

might well be justifiable if the studies were to be undertaken as an experiment and if the results were to be described in the literature. Because of the possible breadth of application and the wide general interest in an undertaking of this kind, it might be possible to obtain financing from sources that might not otherwise provide funds for research on the test method itself.

If such a study should indicate the probability that there would be no substantial financial advantage through improved accuracy of the test method, neither time nor resources would be spent on the method itself. If, conversely, the survey should show the probability of a conspicuous advantage through a more accurate test method, this finding should serve as adequate justification for the allocation of funds by the parties who would benefit most from refinement of the method.

Metallurgy for Non-Metallurgical Engineers?[1]

By JAMES F. YOUNG[2]

This article contributes to the discussion of several of the topics explored at the ASTM-ASEE Symposium on Education in Materials, held during the 62nd Annual Meeting of the Society in June, 1959. Publication of the symposium volume is announced on page 12.

THE solution of modern engineering problems requires a background of training in fundamentals. Such problems seldom occur in well defined form. The initial stage in their solution requires an intuitive ruminating through one's experience to find the problem elements and the related technology. And in this sense, problem solving is an extrapolation of prior experience. When a problem at hand grows logically out of previous practice, the important variables are known, at least intuitively. But when the problem introduces hitherto unknown conditions—as in the earth satellite, the supersonic propulsion plant, the thermonuclear reaction—the only base is an understanding of the variables and the important effects, out of which by analysis and experiment and with perspective and judgment will be determined those variables, principles, and problem elements essential to a concentrated attack upon the problem. Our inability to predict the content of such problems emphasizes the importance of training in fundamentals.

What is the nature of the problems now limiting or forming the barriers to further product improvement? In most every product field the limit today is one of materials. In transformers, for example, the largest single advance in the past 25 years has been the introduction of cold-rolled, oriented, silicon steels. The future should see the control of magnetostriction and higher magnetic saturation as the means for greatest further improvement. In steam turbines, advances to higher temperatures, higher pressures, and larger sizes all await improved metallurgical design. Many other examples could be given to illustrate that materials are the barrier problems in the technical industries. The engineer in these fields requires an understanding of materials that will enable perception of these problems.

The factor-upon-factor of safety is a luxury that is passing from the engineering scene. In the aero and space industries weight is a critical factor. Even where weight is not one of the primary factors in design, it is usually essential to reduce weight, if only to save material cost and shipping cost. It is also true, very often, that reduced weight increases the utility of a product and makes it easier to service. The margin between adequate and competitive design on the one hand and inadequate design on the other is decreasing.

The natural consequence of this trend is the need, on the part of the designer and the manufacturing engineer alike, for a better understanding of the behavior of metals. This includes knowledge of behavior as related to the possibilities, purposes, and exactness of processing techniques; the nature of the residual effects of processing; the manner in which residual effects can provide favorable advantage; and the effects of the conditions of service and its environment.

The training of engineers for work under these conditions requires further attention from industry and the teaching profession. Practice is changing so rapidly under the impact of the growth of science and technology that its teaching might be obsolete before it can be used. Fundamental training in the basic and applied sciences is, therefore, the only foundation on which the curriculum can be built with confidence. With such a foundation, the young engineer can best meet the variety of problems that will arise in industry and can also train himself as he keeps up with the growth of his profession.

The increasing demands on engineering skills require the ability to perceive metallurgical problems, to couple design with metallurgical work, and to interpret metallurgical results in design specifications. It is almost hopeless to expect the young engineer to accomplish this without fundamental knowledge about the structure of materials, their behavior, and the things that influence them. A knowledge of materials is like the third leg on the engineer's stool. It is as essential to the practice of his profession as knowledge of natural phenomena or the industrial arts.

It will not be easy to augment the training of engineers in metallurgy. Somehow, in already crowded curricula, the time must be found. Students and professors alike must be given to realize the importance of such training. New texts are needed, designed specifically for teaching the funda-

PIPE STRESSES

Electric strain gages are used to check stress calculations in prototype structure. Eleventh ASTM Photographic Exhibit. William W. C. Wilke, Jr., Crane Co.

[1] This is a condensation of a paper presented by Mr. Young at a meeting of the Education Committee of the Institute of Metals Division of the American Institute of Mining, Metallurgical, and Petroleum Engineers, at Columbia University, New York, Feb. 19, 1956.

[2] General Manager, General Engineering Laboratory, General Electric Co., Schenectady, N. Y.

mentals of physical metallurgy to nonmetallurgical students. In these, the emphasis should be on fundamental ideas, principles, and methods, rather than on the details of metallurgical diagrams of an alloy or the techniques of polishing and etching.

The teaching of physical metallurgy requires an understanding of the physics of metals and physical chemistry on the one hand, and a knowledge of metallurgical practice on the other. It is difficult to see how this combination can be achieved other than by having the electrical and mechanical departments rely upon the metallurgical department for teaching the subject. The objective of such a program should be to give the student an understanding of (1) the properties of materials as dependent on their internal structure, and (2) the manner in which structure is affected by environment and processing.

There is hope that recent advances in solid-state theory and chemistry may soon form an entirely new and fundamental approach to the study of behavior of materials. The problem of engineering education must, therefore, be a continual one of discarding precepts founded upon art for the more basic principles founded upon science. This has been the pattern in the past; it seems correct to assume that it is the pattern for the future.

District Activities

PITTSBURGH

Bicentennial Science Award

The Pittsburgh District was awarded a "Bicentennial Science Award" plaque for its participation in the science program of the Pittsburgh Bicentennial Celebration. Similar plaques were given to other scientific and professional societies that participated in the program. The citation given with the plaque read "It is the hope of our Science Committee that this award will represent both a token of appreciation and an emblem in years to come of your organization's contribution towards Pittsburgh's growing future."

NEW YORK

Keep Your Pots Clean

"Ladies, the best way to stop your pots from corroding is to keep them clean," so said ASTM President F. L. LaQue, speaking at the New York District Ladies Night Program, January 27. Discussing the Impact of Corrosion on Everyday Life, Mr. LaQue admitted that while corrosion is a problem in the daily life of everyone, most of us are unwilling to do much about it.

The most common corrosion problem faced in our day-to-day living is that of the cooling system in our cars. This is readily cured with inhibitors sold at service stations. Automobile muffler corrosion is another problem. Unless your car is warmed up sufficiently the muffler collects corrosive products and is soon worn out. Get the muffler hot even if your wife has to drive around the block several times after taking you to the station, and your muffler will last much longer, even if your wife doesn't.

In the home, it appears that corrosion is all about us. Water heaters, water pipes, rain spouts, and water space heaters, all are subject to corrosion. The best preventative is good starting materials and sound construction, but this is generally beyond the control of the average householder.

Some housewives have seen their washers explode, spewing soapy suds around the laundry; others have had frothy soda water spout from their kitchen faucet. Both are rare phenomena caused by the evolution of hydrogen formed in certain cases of galvanic corrosion.

With an alternately serious and humorous approach, President LaQue painted a rather grim picture of the havoc corrosion can play in our daily lives. A full-house audience left the dinner meeting with a good appreciation of what corrosion can and does do to affect us daily.

SOUTHEAST

Water Corrosion and Cathodic Protection

Cathodic protection of metals against corrosion by water was the major topic of an address presented by ASTM President F. L. LaQue at the January 26 meeting of the Southeast District. Corrosion and water have been associated in the minds of many of us for years. Manufacturers of tubes, piping, valves, and boilers are concerned with the ability of their products to hold up under a variety of conditions. Equally concerned have been the water technologists, particularly where corrosion products affect the purity of water, its heat-transfer efficiency in either liquid or gas phase, and the disposal of used water.

Mr. LaQue covered both theory and application of cathodic protection, with particular emphasis on evidence that to be of value cathodic protection must be complete, there being no proportional benefit in relation to the degree of partial protection. An exceptionally active question-and-answer period concluded the discussion.

The meeting was cosponsored by the local section of the National Association of Corrosion Engineers and by ASTM Committee D-19 on Industrial Water. Mr. LaQue was well known to those present as a member (and past-president) of the NACE, member of Committee D-19, and president of ASTM. Arrangements for the meeting were made by Mr. James A. Lee, chairman of the Southeast District and Mr. Max Hecht, chairman of Committee D-19.

COMING DISTRICT MEETINGS

Date	District	Place	Speaker
March 9	Ohio Valley	Cincinnati	A. A. Bates
April 19	Western New York-Ontario	Buffalo	F. L. LaQue
April 13	Pittsburgh	Pittsburgh	F. L. LaQue
April 26	Detroit	Detroit	F. L. LaQue

Technical Committee Notes

IN ATTENDANCE AT RECENT CONFERENCE HELD AT ASTM ON PSYCHOPHYSICAL TESTING.

Propose New ASTM Committee On Psychophysical Testing

How does one measure "hand" of textiles; odors in industrial water, paint solvents, and in the atmosphere; odor or taste imparted to foods near or in contact with paper, plastics, or thermal insulation; appearance of painted surfaces, textiles, plastics, or floor waxes? Most of these problems are actively being considered in ASTM committees, and a number of methods for evaluating these properties are in the ASTM Book of Standards. Others not currently under consideration in ASTM technical committees are the subject of inquiries from organizations needing standard test methods. One point in common with all these measurements is that they involve sensory perception; and while instrument methods have been devised to simulate the senses in some cases, in others, such as taste and odor evaluation, the observer *is* the detecting and measuring instrument.

New Committee Proposed

At a conference recently held at ASTM Headquarters which was attended by experts from the government, from independent testing and research laboratories, and from a number of universities, the following general areas, in order of priority, where ASTM activity would seem to be most fruitful, were outlined:

1. Information gathering—literature searching,
2. Communications—standard definitions and nomenclature, and interchange of information,
3. Establishment of principles of psychophysical test methods,
4. Significance and interpretation of tests,
5. Correlation of psychophysical with physical and chemical measurements, and
6. Human response and behavior with respect to materials.

It was the consensus of the conference that ASTM can well serve the national community by establishing a general committee to pool the interest in ASTM with that of other organizations on the general problems of psychophysical testing of materials. It was evident that in the materials field much can be learned from the techniques developed by the food industry. Also, the university teaching of applied psychology will be strengthened by meeting and solving some of the very practical problems now being worked on in ASTM committees.

Plans are to establish an organizing committee from among the conference participants, to select a title and draw up a scope and organizational framework to present to the ASTM Board of Directors for consideration. Those interested in this subject should communicate with Society Headquarters.

New ASTM Committee Will Develop Standard Surfaces; Tests for Slipperiness

A new approach to skid-resistance measurement—use of standard surfaces of known slipperiness—will be attempted by a new ASTM Committee, E-17 on Skid Resistance. At the first meeting of the steering committee, held in Washington, D. C., Dec. 16, 1959. chairman *pro tem* A. T. Goldbeck, engineering consultant, National Crushed Stone Assn., reviewed the story behind the proposed formation of the committee, starting with the International Conference on Skid Prevention held in September 1958, which revealed a need for standardization of equipment and test methods used in measuring skid resistance of pavement surfaces.

The committee's primary task will be to develop standard test vehicles and standard surfaces for calibration purposes. The scope proposed by the steering committee:

1. To develop and standardize field and laboratory methods of test for determining [traffic] surface slipperiness.
2. To develop and standardize methods of test for the use of a set of standards of surface slipperiness.
3. To stimulate research to accomplish objectives (1) and (2).

The list of organizations that have been invited to participate in the activities of the new committee include highway departments, universities, the Tire and Rim Assn., the National Bureau of Standards, and the National Safety Council. It is hoped that the Highway Research Board will be able to stimulate much of the needed research and that the Bureau of Public Roads will be among the organizations that will undertake the necessary field work.

The organization meeting of the committee will be held during the 1960 ASTM Annual Meeting in Atlantic City, N. J., the week of June 26–July 1. Anyone interested in taking part in the activities of the committee should get in touch with ASTM Headquarters.

Wax Friction Tests Reported

Poor reproducibility of results in recently completed interlaboratory tests for static coefficient of friction was reported at a meeting of Committee D-21 on Wax Polishes and Related Materials in Washington, D. C., Dec. 10, 1959. Each participating laboratory used three waxes and pressures of 10, 20, 40, 60, and 80 psi on the sliding shoe of the James machine.[1]

An additional step in the characterization of carnauba wax was taken with the development of two methods for determining resin content.

Methods for the determination of water and abrasive content of automobile cleaners and polishes have been completed. Methods in final stages include procedures for water spotting, removability, and accelerated aging of liquid water-emulsion floor polishes.

[1] The James machine, together with a proposed method of test for its use, are described in the February, 1954 issue of the ASTM BULLETIN, p. 20.

Fracture Testing of High-Strength Sheet Materials:

A Report of a Special ASTM Committee

Editors Note:—The first chapter of this report appeared in the January 1960 issue of the ASTM BULLETIN.

Testing Temperature and Effect of Temperature on Fracture Toughness

The temperature at which a crack-propagation test of a sheet material is conducted is an important factor that can be controlled and varied to broaden the knowledge concerning the behavior of the material. For many high-strength materials there is a characteristic range of temperature (dependent on both the condition of the material and its thickness) in which fracture toughness decreases markedly as the temperature decreases. Since some sheet materials are required to sustain high stresses at service temperatures below the usual range of room temperatures, it is necessary to have information on the toughness of the material at temperatures at least as low as (and preferably lower than) the lowest anticipated service temperature of the contemplated structure. It is desirable to have information on the toughness over the whole range of possible service temperatures.

One example of the variation of the fracture toughness of a sheet material with temperature is shown in Fig. 10(*a*), where the fracture-toughness index used is the K_{c3}-value discussed in the first chapter of this report under Computation of *K*-Values and Practical Applications of K_c-Values. A measure of the fracture appearance—the per cent shear—is also shown in Fig. 10(*a*), but will be discussed later. The material from which these data were obtained was a 0.073-in. thick sheet of an air-hardening steel having the following nominal composition: 0.43 per cent carbon, 1.5 per cent silicon, 2.0 per cent chromium, 0.5 per cent molybdenum, and 0.05 per cent vanadium. The specimens were of the type shown in Fig. 1, with a width, *W* of 1.5 in. and initial crack lengths ($2a_0$) between 0.585 and 0.625 in. (including fatigue crack extensions at the ends of the slot). The specimens were heat treated to have a yield strength at room temperature of about 195,000 psi by air-hardening from 1750 F and tempering twice for 2 plus 2 hr at 1000 F. In this condition, the fracture toughness of the material is much higher than when it is heat treated to its maximum yield strength of about 240,000 psi.

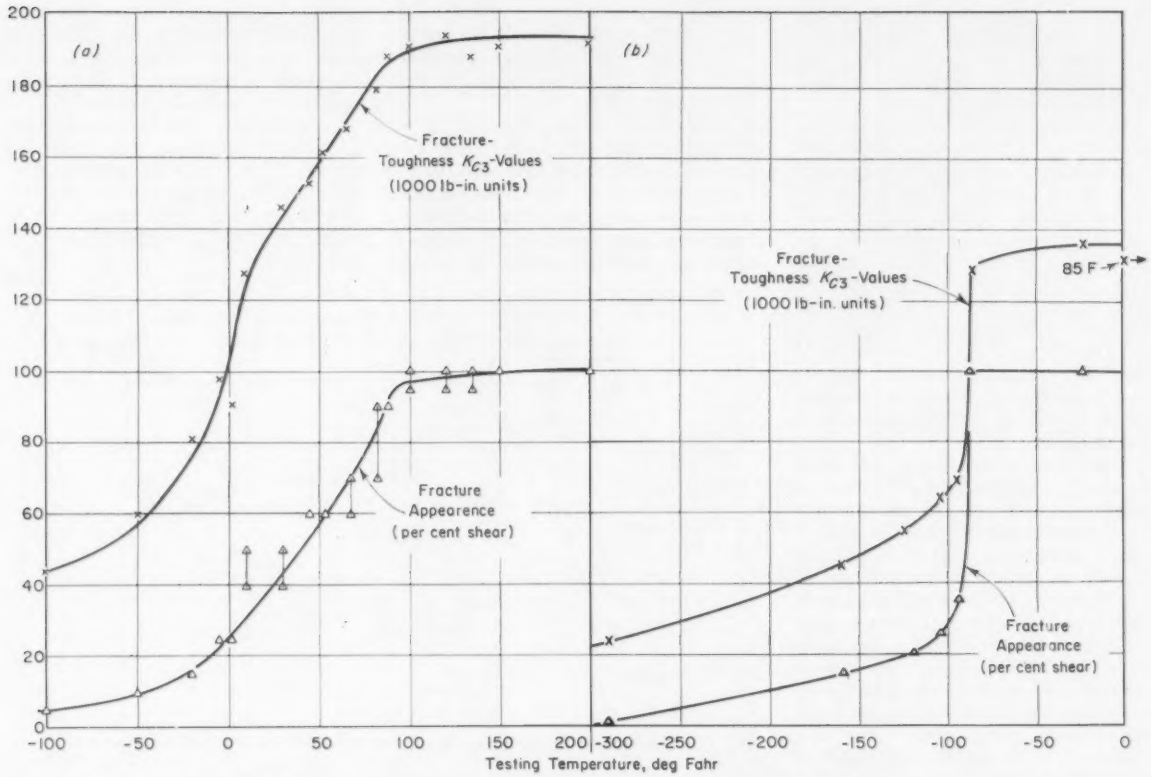
In Fig. 10(*a*) values of K_{c3} greater than 140 are believed to be less accurate than lower values for reasons discussed in the first chapter under Width-to-Thickness Ratio. However, these higher values probably underestimate the more accurate values that would be obtained by testing wider specimens. The points shown for temperatures above about 25 F are, therefore, conservative estimates of K_{c3}. This may account for the reduction in slope of the curve at about 10 F.

The temperature dependence in this case is not as sharp as the temperature dependence observed in many other cases; nevertheless, it is far from being inconsiderable. For example, K_{c3} decreases from a value of 187 at 90 F (a possible testing laboratory temperature) to 173 at 70 F (a possible service temperature)—a difference of 7.5 per cent for the difference of 20 F between these two versions of "room temperature." Since, for a given crack size in a given structure, the maximum nominal stress that can be sustained normal to the crack is directly proportional to K_c, there is a difference of effective strength of the same magnitude. Over the same temperature range, the yield strength changes by only 1 per cent.

A more extreme example is shown in Fig. 10(*b*). In this case, the material was a 0.010-in. thick sheet of a hardenable stainless steel having the following nominal composition: 0.25 per cent carbon, 12.0 per cent chromium, 1.0 per cent molybdenum, and 0.3 per cent vanadium. The specimen width was 0.5 in., the initial crack lengths ($2a_0$) between 0.146 and 0.156 in. The specimens were air-hardened from 1850 F and then tempered for 1 hr at 1050 F, resulting in a yield strength at room temperature of about 165,000 psi. The transition (at −90 F) in Fig. 10(*b*) is much sharper than in Fig. 10(*a*), K_{c3} increasing at least 100 per cent over a range of less than 10 F. It has been observed that, for a given material, the transition is usually sharper the thinner the material and the lower the yield strength.

Associated with the marked change in fracture toughness over a characteristic temperature range, there is a change in the mode of fracture. At low temperatures, the mode of fracture is transverse (the gross-fracture plane is normal to the direction of the applied load) whereas at high temperatures the mode of fracture is oblique shear (the gross plane or planes of separation inclined at about 45 deg to the direction of the applied load, being planes of maximum shear stress). There is a continuous transition between these two modes that takes the form of increasingly wide shear lips, bordering a diminishing central transverse fracture zone as the temperatures increased. At some temperature, the shear borders meet or merge to form a 100 per cent shear fracture. This transition is illustrated schematically in Fig. 11. The description given above refers to the appearance of the fracture beyond a certain distance from the starting front. If this starting front is a crack edge or a sufficiently sharp notch, the transverse mode of fracture will predominate at positions close to the front, but will be gradually restricted by the developing shear lips as the new fracture front moves away from the starting position. The shear lips will reach a more or less constant width, depending on the temperature, at some distance from the starting position, as shown in Fig. 11.

COMMENTS SOLICITED: The ASTM committee writing this report invites the readers to submit comments for consideration. Additional data on this subject would be particularly appreciated. Such correspondence should be addressed to the ASTM Committee on Fracture Testing of High-Strength Sheet Materials, American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.



(*a*) Low-alloy steel sheet 0.073 in. thick; heat-treated to 195,000 psi yield strength at room temperature; specimen width, 1.5 in.; initial crack lengths 0.585 to 0.625 in.

(*b*) Hardenable stainless steel sheet 0.010 in. thick; heat-treated to 166,000 psi yield strength at room temperature; specimen width 0.5 in.; initial crack lengths 0.146 to 0.156 in.

Fig. 10.—Effect of temperature on K_{c3} and per cent shear fracture.

NOTE.—The unit (1000 lb-in.) stated for fracture toughness K_{c3}-values in two places of this figure is in error and should be 1000 lb $\sqrt{\text{in.}}$

In most cases, it is possible to characterize the fracture appearance as the percentage of the thickness of the specimen occupied by both shear borders taken together, usually referred to as the "per cent shear." This is best determined by measuring the width of the central transverse zone, deducting this width from the specimen thickness, and expressing the result as a percentage of the specimen thickness. In Figs. 10(*a*) and (*b*), the per cent shear is plotted, for each specimen, below the corresponding K_{c3}-value to show the similarity of the trend of the two properties. In Fig. 10(*a*), two values of per cent shear are joined by a vertical line to represent the different values measured on the two fracture surfaces on either side of the same center-cracked specimen. There may be some question as to the most suitable position to make the shear-lip measurements. In the first chapter under Test Specimens and Procedure, it is recommended for center-notched specimens that the measurement position should be within two specimen thicknesses from the specimen edge, but no closer than one specimen thickness to the edge. The intent here is to make the measurement at a position where the crack front was moving rapidly, but

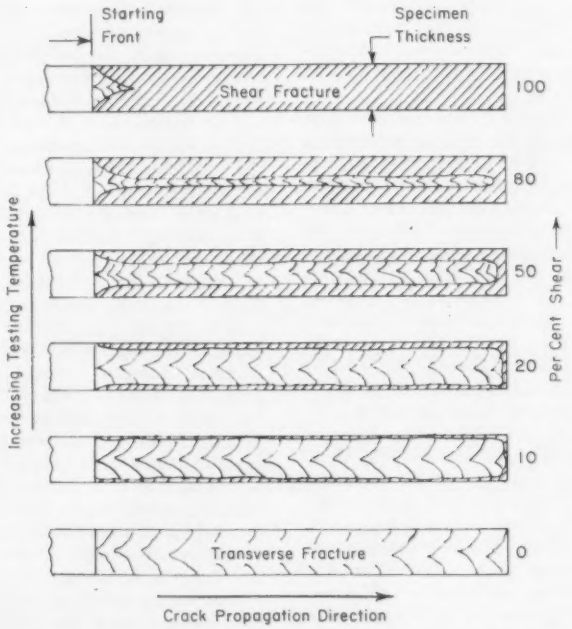


Fig. 11.—Characterization of fracture appearance by percentage of specimen thickness occupied by shear borders (per cent shear) and of effect of temperature in transition range.

far enough from the edge that edge effects were negligible. High-precision measurement is not to be expected; for most purposes, it is sufficient to estimate to the nearest 5 per cent step.

Data on fracture appearance as a function of testing temperature have been published for a number of high-strength sheet steels (**6,7,8**).[1] These results include examples of the effects of thickness and of different heat treatments on the variation of per cent shear with temperature. It has also been shown (**8**) that the per cent shear is not appreciably influenced by the sharpness of the notch or preformed crack in a center-notched specimen, whereas the load at fracture may be profoundly influenced, resulting in spurious values of K_{ca} if the notch is not sufficiently sharp.

The change from 100 per cent shear to some considerably lower value is usually very abrupt. It has therefore been suggested that a fracture-appearance transition temperature (FATT) be defined as the lowest temperature at which the mode of fracture of a specimen would be 100 per cent shear. This would be taken to be 100 F in Fig. 10(*a*) and −90 F in Fig. 10(*b*). For a given material, the fracture toughness decreases rapidly as the per cent shear decreases with temperature. For this reason, it is suggested that materials exhibiting sharp fracture-appearance transitions should not be used at service temperatures lower than FATT. However, the converse does not follow, the fact that FATT is lower than the lowest service temperature is not in itself a guarantee of adequate facture toughness since the fracture toughness for full shear fracturing can vary widely between different materials or between different heat-treated conditions of the same material.

It is important to bear in mind that the thickness of the material has a strong influence on both the fracture appearance and the fracture toughness as discussed in the first chapter under Practical Applications of K_c-Values. At constant temperature, the per cent shear varies from 100 to 0 over a characteristic range of thickness for a given material. At 0 per cent shear, the fracture toughness has an almost constant minimum value, sometimes referred to as the "plane-strain fracture toughness." As the per cent shear increases with diminishing thickness, the fracture toughness increases and may continue to increase somewhat as the thickness is reduced below that level at which the per cent shear first reaches 100 per cent. However, the fracture toughness eventually reaches a maximum value and then decreases again as the thickness diminishes further. This is illustrated in Fig. 5. It is therefore important in conducting tests over a range of temperatures that the thickness of the specimens used should be the same as the thickness of the critically stressed areas in the intended application.

In summary of this chapter, it is important that the temperature dependence of fracture toughness of a material be taken into consideration because for many materials there is a range of temperatures in which the fracture toughness decreases sharply. If the service temperature of the intended application happens to fall within this range, it is to be expected that small variations in temperature will be associated with significant changes in fracture toughness. The fracture-appearance per cent shear also decreases sharply in the transition range of temperature and can be used to determine this range. This characteristic can be particularly useful in investigations of service failures.

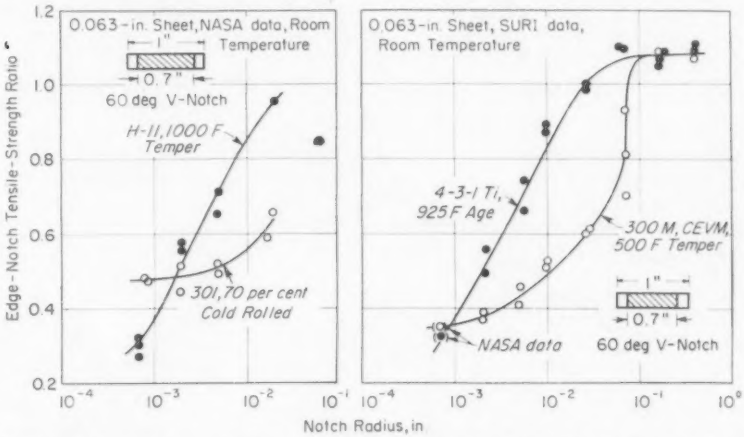


Fig. 12.—Edge-notch tensile strength ratio as function of notch radius for several alloys.

Screening Tests

The second chapter of this report described two tests and a method of analysis designed to yield a quantitative measure of fracture toughness for high-strength sheet alloys. The K-values determined from these tests directly establish an order of merit for such alloys. However, such detailed procedures may not be necessary if the only object is to reveal the tendency toward brittle fracture in the presence of very high stress concentrations. For example, one may desire to know the relative order of merit for a large group of alloys heat treated to a given strength level. Or perhaps it is desired to know the qualitative effect of various heat treatments on the resistance to brittle fracture. Answers to such questions as these may be obtained through a simpler approach based on a single-width specimen and nominal strength values. The more promising alloys selected by the screening test then may be subjected to a more detailed investigation with wide specimens to determine K values.

In selection of a screening test, the following requirements should be kept in mind: (1) the test should permit rapid evaluation of a large number of alloys, metallurgical variables, and testing conditions with a minimum expenditure of time, money, and material; (2) the sensitivity should be sufficient to reveal changes in specimen brittleness as influenced by composition and heat treatment; (3) the test should be easily conducted, even by those with minimum training in stress analysis or metallurgy.

Undoubtedly, there are several tests that may satisfy these basic requirements. Extensive data on a wide variety of alloy conditions are available for two such tests: the edge-notch tension test used by Sachs (**15**) and by Brown and his co-workers (**16**) and the fatigue center-crack test introduced by Srawley (**6,7**). Extensive experience shows that both specimen types satisfy the basic requirements for a screening test.

This chapter is concerned primarily with the sharp edge-notch tension test. The investigator may use fatigue center-crack specimens for the same purpose. However, it should be remembered that, for identical material and testing conditions, these tests will not necessarily yield the same nominal strength values. The various parameters that influence the strength values derived from notched screening tests are described. On the basis of this description the design for a suitable edge-notch tensile specimen is given together with details of specimen preparation, testing procedure, and reporting results.

This chapter concludes with a description of the instrumented bend test, which offers a considerable reduction in specimen preparation and testing time and which had shown correlation with

[1] The boldface numbers in parentheses refer to the list of references appended to this report.

the results of more complex tests. However, experience with this test is limited.

Notched Tension Tests

Test Parameters

The effect of several parameters should be considered in the design of a screening test, including specimen geometry, thickness, loading rate, and eccentricity. This section considers the data pertaining to these variables with a view to establishing the optimum specimen geometry and testing techniques. In the following discussion, attention is directed to data obtained from both edge-notch and fatigue center-crack specimens. Nominal notch-strength values reported are obtained by dividing the maximum load by the minimum initial area in the plane of the notch or crack. In addition, this presentation uses the notch tensile-strength ratio, determined by dividing the notch strength by the corresponding ultimate tensile strength for the same alloy and under the same testing conditions.

Notch Radius.—The evidence so far available indicates that the edge-notch strength is influenced by the notch-root radius to an extent dependent on the alloy. Figure 12 shows data for several alloys tested at room temperature using 1-in. wide specimens having 0.15-in. deep edge notches provided with various root radii. The radius effect may be rather complex, as shown for alloy 300M, which exhibits a transition at a rather large radius (0.070 in.). Other materials may exhibit the same effect if tested at certain temperatures or hardness levels. All the data, except for AISI type 301 and alloy 300M, show considerably lower strength when the radius is reduced from 0.002 in. to a value of 0.0007 in. maximum. Figure 13 shows more complete data for the strength of H-11 steel as a function of tempering temperature. It is evident that a considerable gain in sensitivity of the edge-notch test occurs when the radius is reduced from 0.002 to 0.0007 in. maximum.

The question always arises as to the effect of further radius reductions and, in particular, how the strength of sharp edge-notch specimens compares with fatigue center-crack specimens. Some recent results are shown in Fig. 14 for tests on a single heat of low-alloy steel derived from both 1-in. wide fatigue center-crack specimens and edge-notch specimens having an 0.0007-in root radius. In both cases, the total notch length is approximately 0.30 in. It is evident that the sharp edge-notch test yields lower strength values at tempering temperatures less than about 1000 F. Other evidence of this type indicates that the difference in strength values varies with the alloy. However, no available data indicate that natural cracks

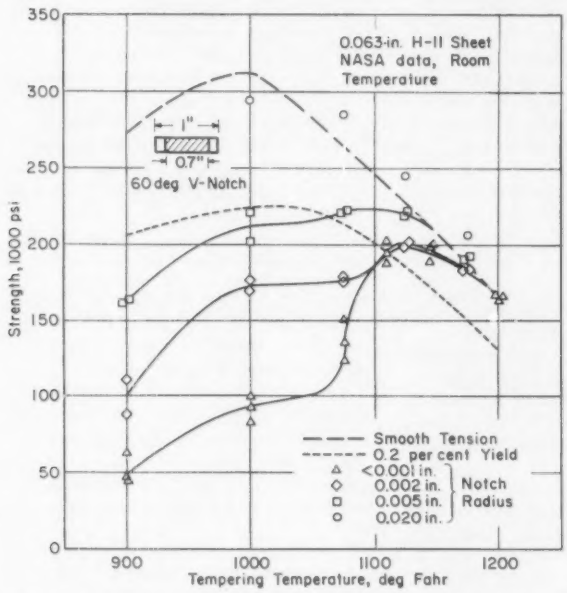


Fig. 13.—Effect of notch radius on edge-notch strength of H-11 steel tempered at various temperatures.

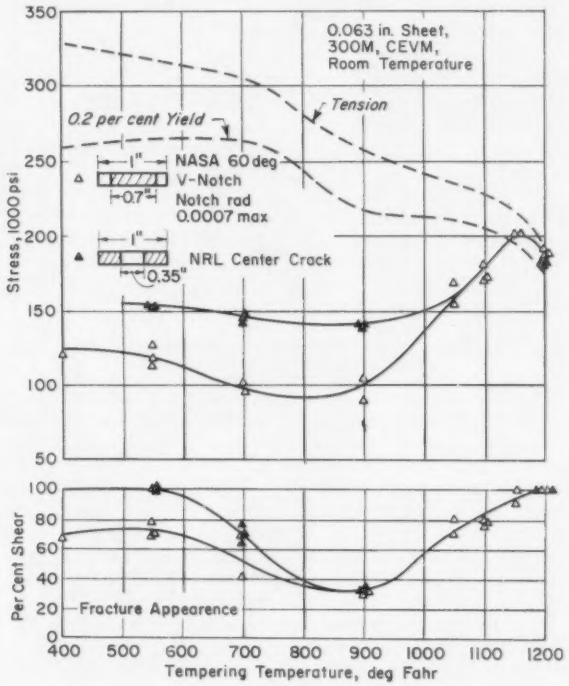


Fig. 14.—Sharp edge-notch strength, fatigue center-crack strength, and fracture appearance for 300M steel tempered at various temperatures.

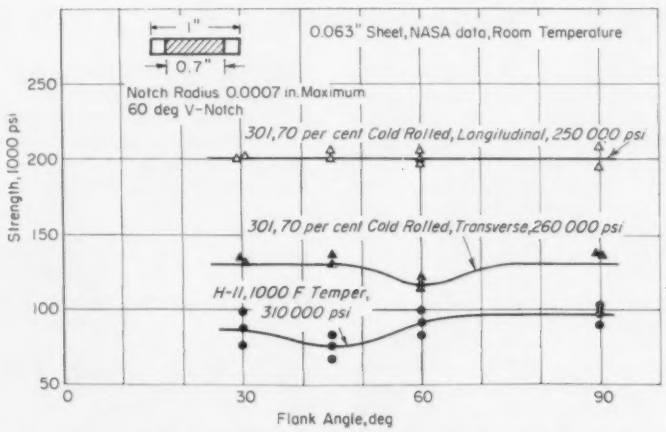

0.063" Sheet, NASA data, Room Temperature
Notch Radius 0.0007 in. Maximum
60 deg V-Notch
301, 70 per cent Cold Rolled, Longitudinal, 250 000 psi
301, 70 per cent Cold Rolled, Transverse, 260 000 psi
H-11, 1000 F Temper, 310 000 psi
Strength, 1000 psi
Flank Angle, deg

Fig. 15.—Effect of flank angle on sharp edge-notch strength for two alloys.

give greater embrittlement than very sharp machined notches.

The sharp edge notches used by Brown and his co-workers are specified to have radii of 0.0007 in. maximum. Accurate radius measurements of less than this value are difficult to make. It may be assumed, however, that the actual values vary, with 0.0007 in. as an upper limit. If the effect of this variation were large, 45 deg for longitudinal tests on H-11 steel. Thus, a small increase in sensitivity of the sharp edge-notch test may be possible by selection of the optimum flank angle. However, since the great majority of available data relates to a 60-deg angle, it is recommended that the screening test employ this value.

Notch Depth.—It was pointed out in the first chapter that stress analysis psi per mil for a 12 per cent chromium steel tested at room temperature. As pointed out by Irwin (1), a decrease in fracture toughness and a shift from oblique shear to flat cleavage fracture would be expected with an increase in specimen thickness. This is due in part to the approach to plane-strain fracture conditions as the thickness increases. The observed thickness effect also con-

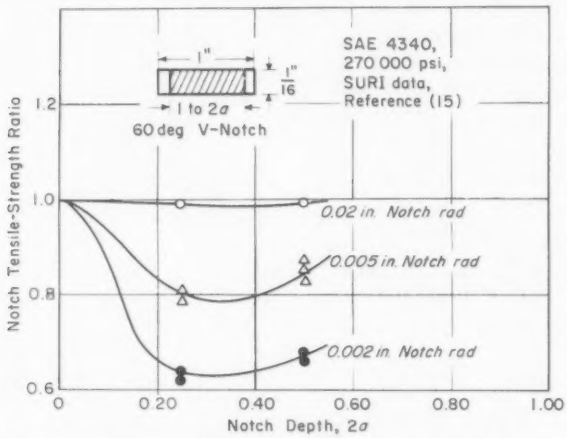


Fig. 16.—Edge-notch tensile-strength ratio as function of edge-notch depth for several notch radii.

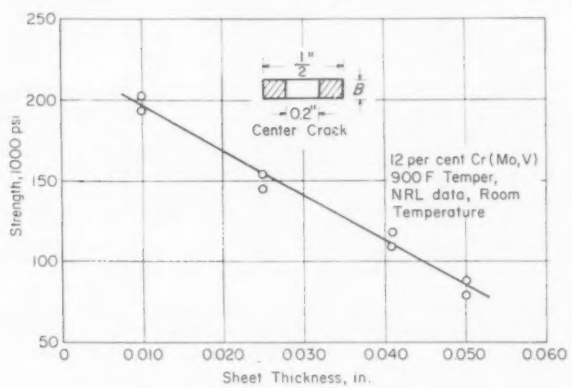


Fig. 17.—Effect of sheet thickness on center crack-strength.

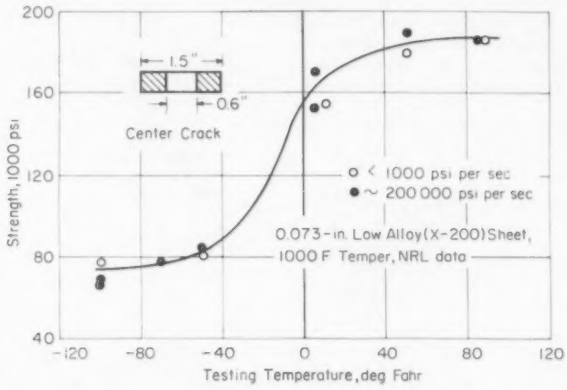


Fig. 18.—Center crack-strength as function of testing temperature for two loading rates (load determined with strain-gage bar).

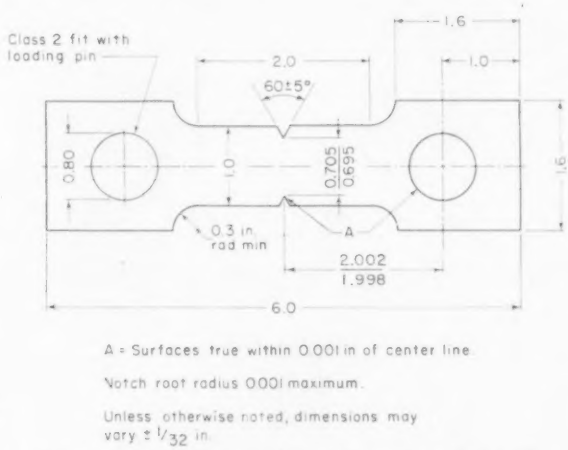


Fig. 19.—Proposed sharp edge-notch screening specimen.

it would be revealed in strength scatter for otherwise identical specimens. Since the observed scatter is quite small, it is probable that the radius effect fades out at values below about 0.001 in.

On the basis of the available evidence it is recommended that sharp edge-notch specimens be provided with a notch radius of 0.001 in. maximum.

Notch Angle.—Limited data are now available for the effect of notch angle on two widely different alloys, AISI type 301, cold-rolled 70 per cent, and H-11 steel, tempered at 1000 F. The results, Fig. 15, are rather unexpected in that a slight minimum in sharp edge notch strength occurs at about 60 deg for transverse tests on AISI type 301 and at about shows a minimum in the edge-notch net-section stress would be expected at a total depth of about 0.4 times the width. Data obtained by Sachs et al (15), who used specimens of various root radii, show a minimum in edge notch tensile-strength ratio between a notch depth of 20 and 40 per cent (Fig. 16). Considerable data are now available on the basis of 30 per cent depth. Since this is in the range that renders maximum notch sensitivity, it is recommended for the screening test.

Effect of Thickness.—As shown by Srawley (17), the strength of center-crack specimens decreases with increase in thickness. According to Fig. 17, this effect can amount to as much as 3000 tains a metallurgical (structural) component that is complex in nature and depends on the stability of the alloy and the rolling conditions. However, other factors being equal, the thinner material would be expected to have the higher fracture toughness if the lighter gage was worked more severely.

The conclusion is that the alloy in question should be tested in the thickness used in service. Furthermore, comparisons between different alloys should be made only for the same thickness and preferably from sheets not differing widely in the amount of reduction to the final gage.

Specimen Width.—For the *K*-value test, discussed in the first chapter, the

width-to-thickness ratio was recommended to be at least 16 and no greater than 45. In the case of a screening test, it appears that a single-width specimen may be used. Considerable data have already been obtained for 0.063-in. thick sheet alloys by use of 1-in. wide 30 per cent edge-notch specimens (**15,16**). For the materials investigated, this width provides ample sensitivity for the purpose of screening high-strength alloys. The use of this specimen for material 0.063 in. or less meets the width-to-thickness requirements set forth in the first chapter.[8] For thicker sheets, the width-to-thickness ratio will be less than 16. Loss in sensitivity due to a decrease in this ratio is compensated in part by the tendency of thicker specimens to fail at lower average stresses (Fig. 17).

Effects of Testing Speed.—There are very few data directly bearing on the influence of testing speed. Irwin (**10**) has pointed out that the dynamic increase in yield strength for tempered martensites is relatively small. Therefore, it may be inferred that the sharp-notch strength is insensitive to strain rate over a certain range. However, it is difficult to connect directly the results of smooth-bar strain-rate tests to the behavior of notched specimens. Srawley (**17**) has obtained some data for center-crack specimens of a low-alloy steel, tested at loading rates of 1000 and 200,000 psi per sec. Tests carried out over a range of temperature show no effect of this variation in rate (Fig. 18). However, different results might be expected if the alloy were unstable during the test. Thus, it is known that the room-temperature dynamic yield strength of metastable austenitic stainless steels is very sensitive to the strain rate. Furthermore, if the test temperatures are sufficiently high to cause creep, strong rate effects would be expected.

In the absence of additional data, it is recommended that the loading rate be between 1000 and 10,000 psi (net-section stress) per sec. While faster loading rates may not influence the true strength it may not be possible to read the true loads on some commercial testing machines.

Specimen Design, Preparation, and Testing Procedure

On the basis of the preceding discussion, it is possible to recommend a suitable screening specimen and testing procedure. The edge-notch specimen is emphasized in the following discussion; however, details of the fatigue center-crack specimen are also given.

Specimen Design.—The geometry of the edge-notch screening specimen should meet the following requirements: (1) permit pin loading, (2) 1-in. width, (3) notch radius of 0.001 in. maximum, (4) flank angle of 60 ± 5 deg, and (5) notch depth of 0.15 to 0.17 in. on each side. The sharp edge-notch specimen, shown in Fig. 19, meets these requirements. Heads have been provided so that the most ductile specimens fracture in the notch. This is particularly necessary when notch-to-tensile strength ratios are to be determined (see below). When the nominal notch strength is below the yield strength, straight-sided specimens may be used. The pin hole should then be changed to about $\frac{3}{8}$ in. diameter. Since this is a somewhat marginal condition regarding shear in the pin, very hard pins should be employed.

Particular care should be taken to dispose the notches symmetrically to the loading axis in order to minimize loading eccentricity (Fig. 19).

It has been shown by Sachs et al (**18**) and Jones et al (**19**) that a small eccentricity of loading can introduce bending stresses which significantly reduce the strength of circumferentially notched round bars, heat treated to high hardness levels. Eccentricity can arise from misalignments in the loading system or misalignments inherent in the specimen. These can vary in a random manner from test to test and result in apparent scatter of data for identical specimens.

There are no direct data relating to the influence of eccentricity in notch testing of sheet. Bending moments perpendicular to the notch plane (sheet surface) are of no great consequence because of the relatively high length-to-thickness ratios generally encountered. Bending moments in the sheet plane are minimized by careful attention to the specimen machining and by rotation of the specimen about the pins. The results obtained with specimens similar to those shown in Fig. 19 show very little scatter and it may be concluded that the eccentricity was quite low.

Specimen Machining—The specimen machining procedures outlined here are designed to insure the maintenance of the tolerances specified in Fig. 19. Undoubtedly, other successful methods could be developed.*

The preparation of center-crack and sharp edge-notch specimens is quite similar up to the introduction of the notch. Conventional machining methods may be used to produce the general specimen contour.

Machining is carried out in a pin jig having a ±0.0002-in. clearance between the pin holes and the pins on the jig. Groups of specimens may be clamped together in this jig. The head radius on one side is then ground or cut to size and the test section on the same side finished by grinding or milling. The specimens are then turned on the pin jig and the same operations repeated on the other side. Edge-notch specimens are now ready for notching.[9] Center-crack specimens require a crack starter in the form of a center slot, which may be introduced at this stage of machining by electrical discharge machining. A piece of $\frac{1}{64}$-in. thick brass shim stock of the proper width is used as a tool. The resulting slot is about 0.020 in. wide and has rather blunt corners.

Sharp edge notches can be most economically prepared when roughed by grinding. Specimens remain in the pin jig and a surface grinder is used to produce a root radius from 0.005 to 0.007 in. A $\frac{1}{2}$-in. thick A120J alundum wheel is dressed to a 60-deg angle, dead sharp for this operation. Roughing to approximately 0.005 in. of final depth can be done with two or three redressings. Coolant is applied through the wheel. The final radius is produced by fixing a carbide tool in the head of a milling machine and by drawing the specimen under the tool by movement of the bed. Generally, only one specimen can be worked at a time. The tool is diamond ground to a point and to within ±1 deg of the notch angle produced by the previous grinding. Several cuts and tool regrinding operations may be necessary to produce a radius of 0.001 in. maximum. During this procedure, the notch radius must be frequently examined with an optical comparator preferably of 100× magnification. When replacing the tool, particular attention should be given to proper alignment with respect to the notch. This can best be accomplished with a low-power microscope mounted on the milling machine.

In the case of center-crack specimens, the slots are extended by fatigue cracks to provide over-all crack lengths of 0.33 to 0.35 in. As a guide to the fatigue machine operator, lines are lightly scribed parallel to the specimen axis and at an appropriate distance from the slot ends. The specimen is then mounted in a fatigue machine and loaded in tension-tension, the maximum load corresponding to a net-section stress not more than one half the yield strength and the minimum load sufficient to eliminate excessive vibration. The operator, using suitable illumination and a hand lens, stops the fatigue machine when the crack tips meet the scribed lines. On the average, the process takes about 15 min per specimen and requires about 20,000 cycles.

The edge notch might also be sharp-

[8] When $W/B > 45$ buckling may occur in the notch plane. This will reduce the strength values but should not decrease the test sensitivity.

* See paper by March et al on "Machining of Notched Tension Test Specimens," p. 52 of this publication.

[9] If the stock is sufficiently soft, the specimens can be roughed by die blanking. If blanking is used or if the specimen is to be heat-treated before notching, finish dimensions except pin holes should be made about 0.025 in. oversize. Then, finish machining is performed as described to produce the final contour. The pin holes may require honing after heat treatment.

ened by the introduction of fatigue cracks. This would probably be more difficult to accomplish in a symmetrical manner than for the center-slotted specimen if tension-tension is used. However, the specimen could be subjected to alternating bending with the moments in the sheet plane, and the stress varied from tension to zero on one side until a crack of the desired length is produced. The specimen could then be reversed in the fixture to produce a crack on the opposite side. Fatigue cracks under such conditions would be running into a decreasing stress field and should be easily controllable.

Specimen Heat Treatment.—The question as to whether the specimens should be heat treated before or after notching—and in what environment—is not easy to answer with the limited amount of information available.

Srawley (8) has tested fatigue center-crack specimens of a low-alloy steel that were cracked either before or after complete heat treatment. Austenitizing was performed in argon, followed by air cooling and tempering in air at 700 F. The data (Fig. 20) indicate no difference in the strength or fracture appearance for the two series. These results would indicate that it makes no difference whether the notching is performed before or after heat treatment, provided there is good atmosphere control. However, it cannot be assumed that the same conclusions would apply to another high-temperature environment.

It is recommended that specimens be heat treated after final machining, in the same manner as used for the service components. This has the advantage that notching may be performed with the specimen in a soft condition. Care should be taken that twisting does not occur during quenching. This has not been a problem with the specimen type shown in Fig. 19.

Testing Procedure.—The specimens should be loaded by pin yokes similar to those shown in Fig. 21. Ground carbide pins have been used that have a class 2 fit with the specimens holes. The use of carbide permits testing at elevated temperatures and has the added advantage that hard metal specimens will not roughen the pin surface. Generally, the slot in the yoke is made several mils larger than the largest anticipated specimen thickness. Any clearance is then taken up with sheet metal shims. The use of a tapered drift pin assists in aligning the shims and specimens properly. This drift pin is pushed through the pin hole in the yoke by the loading pin which then remains in place.

Dimensional tolerances on the yoke are not particularly critical since bending moments are reduced by specimen rotation about the hard loading pin. The yoke, of course, should be of sufficient strength to withstand the highest anticipated load without yielding. However, if made of heat-treated steel, the hardness should not exceed about Rockwell hardness C 38 in order to avoid brittle fracture at points of stress concentration. If tests are to be made at low temperatures, this hardness level may have to be further reduced depending on the alloy. If tests are to be made at elevated temperatures, a material should be used that exhibits no creep at the highest anticipated temperature.

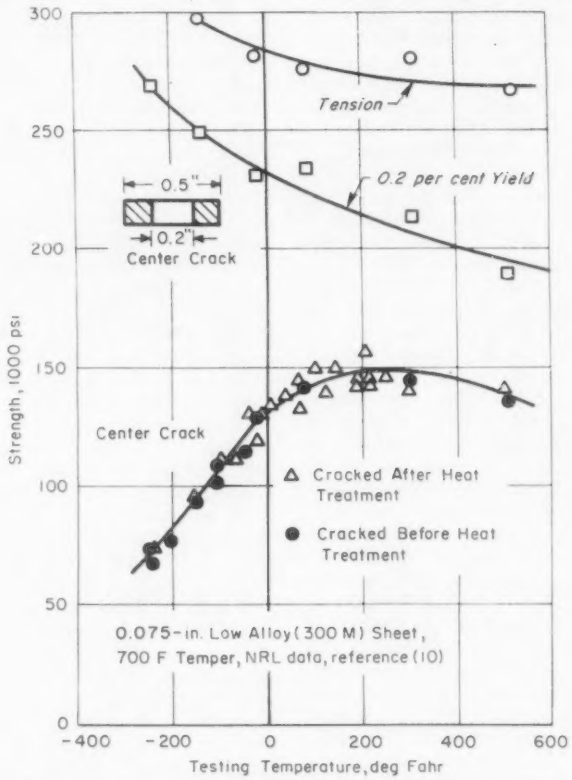


Fig. 20.—Center crack-strength as function of testing temperature for specimens fatigue-cracked before or after heat treatment.

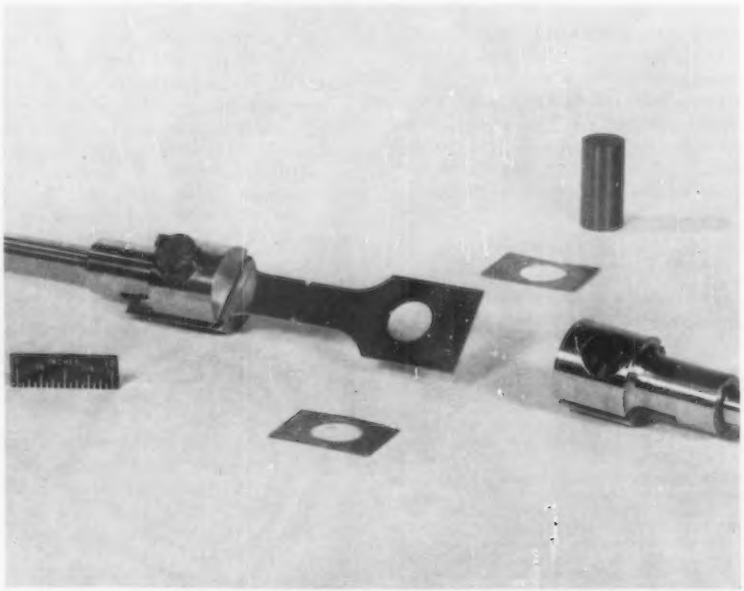


Fig. 21.—Pin-loading yoke assembly.

Care should be taken during initial loading that no impact loads are applied; the loading rate should be between 1000 and 10,000 psi (net-section stress) per sec for tests on stable alloys at room temperature and below. For elevated temperature tests where creep is a problem, no definite recommendations can be made. However, closer control of the loading rate would be essential.

material has a value of K_c at least that necessary to arrest a through-the-thickness crack of twice the thickness. If $B>0.063$ in. and if $\sigma_{NS} \geq \sigma_{YS}$, the material has a value of K_c at least sufficient to arrest a 0.125-in. through-the-thickness crack. These relations follow from the first chapter, section on Width-to-Thickness Ratio and section on Practical Applications of K_c-Values, Eq. 5. Therefore, a value of unity has no particular basic significance, and values above unity may still indicate notch sensitivity depending on the ratio of yield strength to tensile strength.

The significance and methods of reporting fracture appearance have been discussed in detail in the third chapter. For the screening test, essentially the same interpretations should be made.

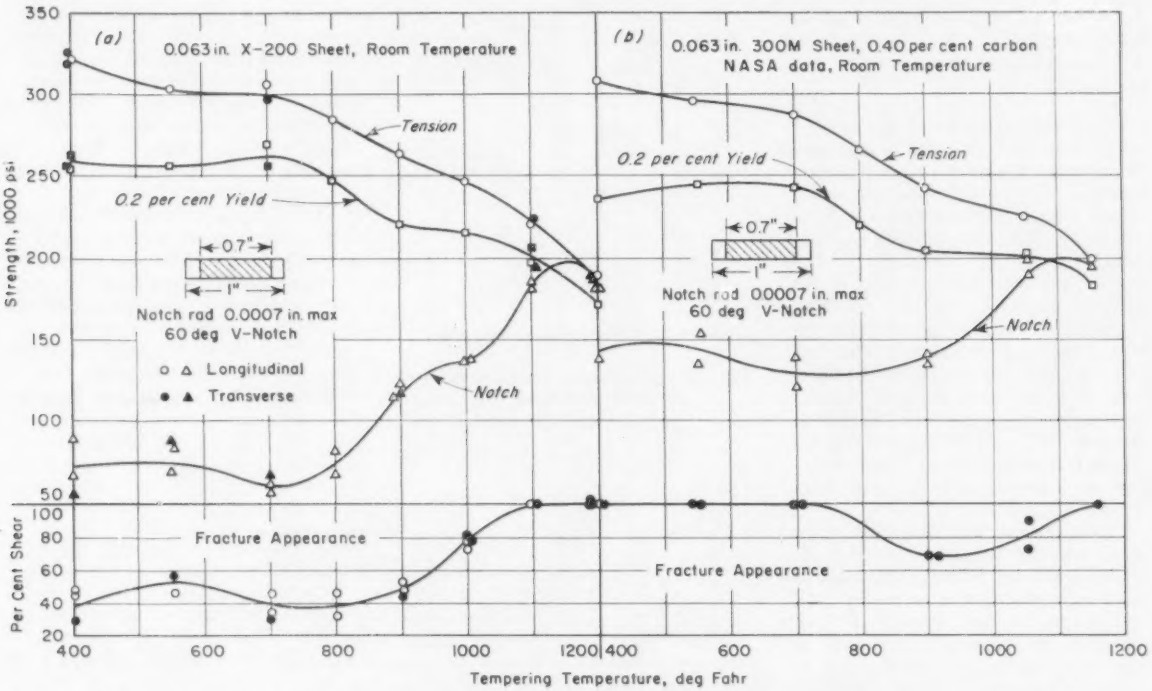


Fig. 22.—Sharp edge-notch and smooth tensile strength and fracture appearance of sharp edge-notch specimens as function of tempering temperature.

Reporting of Results

On the basis of available evidence, the nominal notch strength and a measure of fracture appearance should be reported together with the corresponding smooth ultimate and 0.2 per cent yield strength.

The notch strength is defined as:

$$\sigma_{NS} = \frac{P_{max}}{B(W - 2a_0)}$$

where P_{max} is the maximum load, B the sheet thickness, W the specimen width, and $2a_0$ the total initial notch depth. The corresponding smooth strength values should be obtained using specimens heat treated in exactly the same manner as the notch specimens. It is recommended that preferably triplicate, but at least duplicate, notch tests be made for each metal condition to be investigated.

If $\sigma_{NS} \geq \sigma_{YS}$ and $B \leq 0.063$ in., the since $\sigma_{NS} \leq \sigma_N$ under all conditions.

It is also recommended that the ratio between the notch strength and the tensile strength, designated as the sharp edge-notch tensile-strength ratio, be reported. This quantity is equal to or slightly above the tensile strength if there has been sufficient plastic flow to eliminate the elastic stress concentrations.

Values below unity indicate various degrees of notch sensitivity or, stated differently, the inherent resistance to brittle fracture decreases with a decrease in this ratio. The screening test is no longer sensitive to embrittling factors when this ratio is unity or above.

In addition, a ratio may also be formed between the notch strength and the yield strength. This ratio is designated as the "sharp edge-notch yield-strength ratio." It has the advantage that the strength of the notch specimen is compared directly to a stress usually emphasized in design. Its disadvantage is that σ_{YS} is a purely arbitrary number defined differently by different people.

It appears that for heat-treated steels, 100 per cent shear fractures always characterize material or testing conditions producing sharp-notch strengths equal to or higher than the yield strength. Typical behavior is shown in Fig. 22(*a*) for X-200 steel, tempered at various temperatures and tested at room temperature. However, 100 per cent shear is a necessary but not sufficient condition for high fracture toughness. For example, alloy 300M with 0.40 per cent carbon exhibits 100 per cent shear at tempering temperatures below about 700 F with sharp-notch strengths well below the yield strength (Fig. 22(*b*)).

Instrumented Bend Test

The instrumented bend test[10] is a crack-propagation test wherein a small unnotched rectangular specimen is biaxially stressed to failure by bending as a simple beam under three-point loading. This test provides a crack-propagation-resistance parameter that correlates with other types of crack-propagation tests and with pressure-vessel behavior.

[10] Developed by Allison Division, General Motors Corp.

Description of Test

Test Specimen.—Most of the instrumented-bend-test data have been obtained using a specimen 0.052 by 0.700 by 1.5 in. These dimensions were chosen for two reasons:

1. A specimen of this size can easily be obtained from subscale as well as full-scale rocket motor cases after burst testing.
2. The width-to-thickness ratio of approximately 14 provides an adequate 2:1 biaxial stress area approximately $\frac{1}{2}$ in. in width.

Specimens of other thickness and width may be used, but a minimum width-to-thickness ratio of 10 is recommended. The width and thickness should remain constant when results of different materials or processes are compared.

All specimens are ground to the finished dimension without breaking sharp edges. The surface finish is not critical—as long as grinding burns are avoided—with the normal surface finish ranging from 10 to 20 rms. Surface finishes ranging from 10 to 150 rms do not essentially change the test results. No mechanical notches or cracks of any kind are necessary in the preparation of these test specimens.

Equipment and Instrumentation.—Basically, the test consists of bending the specimen as a simple uniform rectangular beam supported at two points by $\frac{1}{4}$-in. rounds and loaded through a $\frac{1}{8}$-in. round at the center of a 1-in. span, as shown schematically in Fig. 23.

All components of the bend test fixture are made from tool steel, hardened and tempered to Rockwell hardness C 60. The rate of deflection is maintained constant in a tension testing machine with a crosshead speed of 0.5 in. per min. This value is not critical within the range of 0.5 to 2.00 in. per min. The load on the specimen is sensed during the test by a resistance strain gage load cell (1000 lb capacity) placed between the bend test fixture and the lower platen of the tension testing machine. The output of the load cell is fed into a strain-gage amplifier and recorder. The recorder must have sufficient pen speed response to track the load on the specimen accurately without lag. An oscillographic type recorder with a frequency response of 60 cps or higher is recommended. The strain gage load cell and the recorder are calibrated against the tension testing machine so that each division of the recorder strip chart is usually equivalent to 20 or 25 lb of load. The chart paper is usually driven at 5 mm per sec. The strip chart of the recorder thus furnishes a continuous record of the specimen load as a function of time during the test.

Interpretation and Calculation of Test Results

Typical load-time curves obtained from instrumented bend tests conducted on a high-strength steel, heat treated to uniaxial 0.2 per cent yield strength levels of 245,000 psi (SN 5) and 197,000 (SN 4), are shown in Fig. 24.

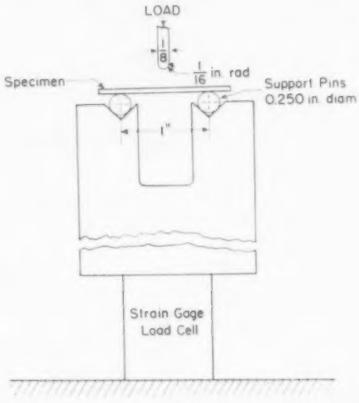


Fig. 23.—Schematic representation of instrumented bend test.

Both curves show the same general behavior: The load increases to maximum value, then decreases at a relatively slow rate until a lower load is reached at which time there is a very rapid change in the rate of unloading. The maximum load is indicated by P_m, and the load at which the rapid change in rate of unloading begins is denoted by P_1.

Observation of the tension face of specimens during the test has shown that the first cracks appear in the center biaxially stressed area at the P_m load and progress by slow crack propagation until P_1 load is reached, when rapid crack propagation occurs. Figure 25 shows ink-stained fractures demonstrating slow crack progression as the load decreases from P_m to P_1.

The first step in the calculation of the instrumented bend test parameter is to pick P_m and P_1 from load-time curves. A sharp change in the shape of the load-time curve is required to accurately pick P_1. When materials approach low strength levels, the P_1 point is not distinct, and reliable parameter calculations cannot be made. These loads are

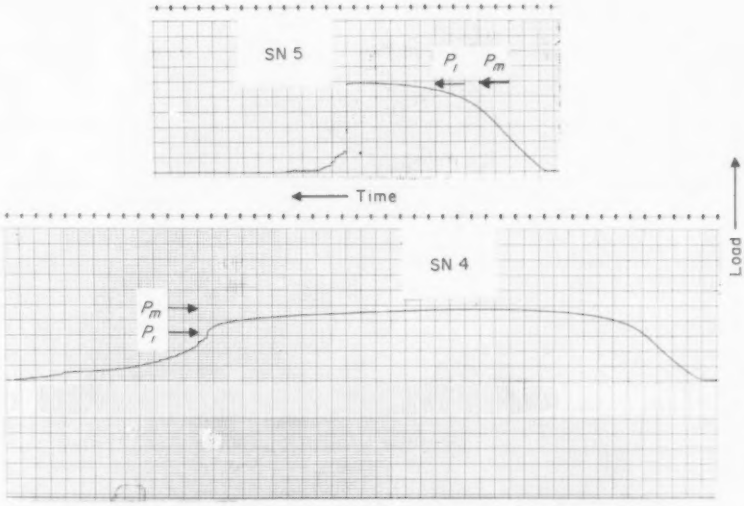


Fig. 24.—Recording charts for instrumented bend test.

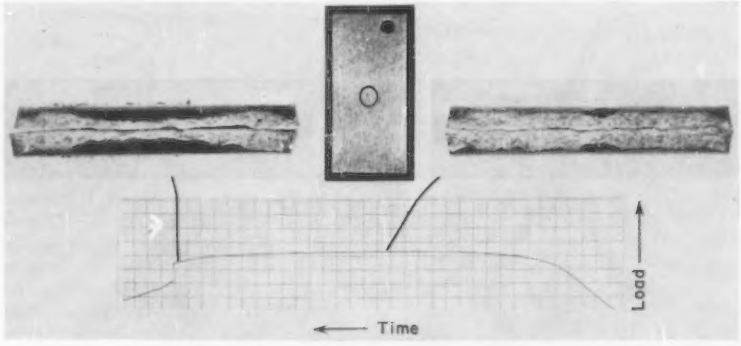


Fig. 25.—Crack propagation in instrumented bend test.

TABLE VI.—TEST RESULTS FOR H-11 STEEL SHEET.

Specimen	Tempering Temperature, deg Fahr	Rockwell Hardness, C-scale	Instrumented Bend Test, $\sigma_m - \sigma_1 \times 10^{-5}$, psi	Center-Crack Tension Test (Specimen 0.095 in. Thick)				Uniaxial Tension Test		
				K_c, psi/$\sqrt{\text{in.}}$	Per Cent Shear	Net Fracture Stress, psi	Net-Fracture Stress/σ_y	σ_y, 0.2 per cent Yield Stress, psi	Ultimate Tensile Strength, psi	Elongation in 2 in., per cent
V6-1	600	53–54	0.33	89 000	50	136 000	0.59	230 000	296 000	8.5
2	600	53–54	0.22	61 500	44	133 000	0.58	232 000	296 000	8.5
3	600	53–54	0.25	74 500	48	133 500	0.58	230 000	293 000	8.2
4	600	53–54	0.47	67 000	56	135 000	0.59	...	...	...
5	600	53–54	0.40	90 000	56	140 500	0.61	...	...	...
6	600	53–54	0.48	61 500	48	147 000	0.64	...	...	...
V8-1	800	53–54	0.22	31 500	26	85 000	0.36	242 000	290 000	12.1
2	800	53–54	0.07	...	...	...	...	240 000	291 000	11.3
3	800	53–54	0.11	...	23	93 000	0.39	...	...	...
4	800	53–54	0.07	35 000	20	81 500	0.34	...	...	...
5	800	53–54	0.18	32 000	22	90 000	0.37	...	...	...
6	800	53–54	0.15	26 700	17	63 600	0.26	...	...	...
V10-1	1000	54–55	0.04	26 800	0	75 500	0.31	236 000	304 000	8.9
2	1000	54–55	0.14	18 000	0	61 800	0.26	244 000	310 000	8.3
3	1000	54–55	0.04	19 300	0	60 900	0.25	...	...	...
4	1000	54–55	0.07	20 700	0	61 800	0.26	...	...	...
5	1000	54–55	0.07	17 500	0	56 000	0.23	...	...	...
6	1000	54–55	0.11	...	...	...	...	...	...	...
V11-1	1100	46–47	0.94	110 000	100	206 000	1.02	205 000	236 000	10.6
2	1100	46–47	0.92	104 000	100	198 000	0.98	202 000	233 000	10.4
3	1100	46–47	0.83	98 000	100	204 000	1.00	200 000	235 000	10.6
4	1100	46–47	0.95	97 000	100	201 000	0.99	...	...	...
5	1100	46–47	...	117 000	100	198 000	0.98	...	...	...
6	1100	46–47	1.02	114 000	100	204 000	1.00	...	...	...

corrected for small dimensional differences in the thickness and width of different samples by converting to maximum outer fiber stress, σ_m and σ_1, by means of the beam formula:

$$\sigma = \frac{3PL}{2wt^2}$$

where:

σ = maximum outer fiber stress, psi,
P = load, lb,
L = distance between supports (1.00 in.),
t = thickness of specimen (0.052 in. nominal), and
w = width of specimen (0.700 in. nominal).

The difference between σ_m and σ_1 then represents the reduction in the calculated highly localized outer fiber stress in the specimen due to slow crack progression before rapid crack progression occurs. The instrumented bend test parameter is defined as $\sigma_m - \sigma_1$. The values calculated from the two curves in Fig. 24 were 0.26×10^5 psi for SN 5 and 1.45×10^5 psi for SN 4.

Correlation of $\sigma_m - \sigma_1$ with Other Tests

Center-Crack Tension Tests.—The instrumented bend test parameter $\sigma_m - \sigma_1$ has been correlated with the results of center-crack tension tests conducted on H-11 steel, heat treated to various strength levels, as shown in Fig. 26 and Table VI.

Since the instrumented bend test parameter correlates with K_c and other parameters derived from the more complex center-crack tension test, it should serve as a simple, rapid screening test for crack-propagation resistance of high-strength materials.

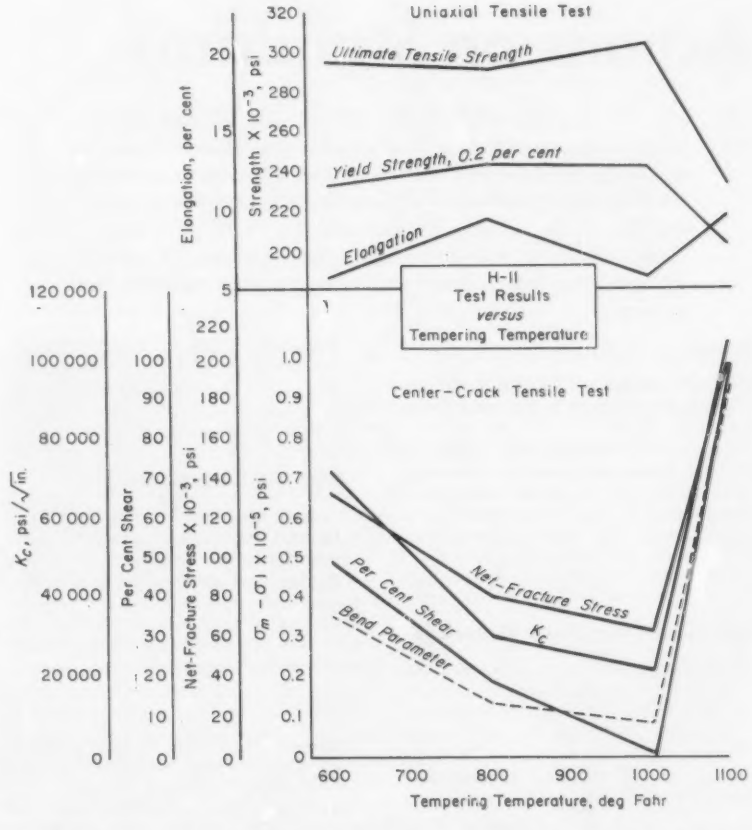


Fig. 26.—Correlation of instrumented bend test parameter with center-crack tests.

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Readers of this report are invited to comment on the proposed test methods and on other methods that have not come to the attention of the committee.[11]

REFERENCES

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[11] Correspondence should be addressed to ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa.

Actions on Standards

curately define the quality of ozone resisting butyl insulation being produced.

Plastics

the fixture to produce a crack on the opposite side. Fatigue cracks under such conditions would be running into a decreasing stress field and should be easily controllable.

Specimen Heat Treatment.—The question as to whether the specimens should be heat treated before or after notching—and in what environment—is not easy to answer with the limited amount of information available.

Srawley (8) has tested fatigue center-crack specimens of a low-alloy steel that were cracked either before or after complete heat treatment. Austenitising was performed in argon, followed by air cooling and tempering in air at 700 F. The data (Fig. 20) indicate no difference in the strength or fracture appearance for the two series. These results would indicate that it makes no difference whether the notching is performed before or after heat treatment, provided there is good atmosphere control. However, it cannot be assumed that the same conclusions would apply to another high-temperature environment.

It is recommended that specimens be heat treated after final machining, in the same manner as used for the service components. This has the advantage that notching may be performed with the specimen in a soft condition. Care should be taken that twisting does not occur during quenching. This has not been a problem with the specimen type shown in Fig. 19.

Testing Procedure.—The specimens should be loaded by pin yokes similar to those shown in Fig. 21. Ground carbide pins have been used that have a class 2 fit with the specimens holes. The use of carbide permits testing at elevated temperatures and has the added advantage that hard metal specimens will not roughen the pin surface. Generally, the slot in the yoke is made several mils larger than the largest anticipated specimen thickness. Any clearance is then taken up with sheet metal shims. The use of a tapered drift pin assists in aligning the shims and specimens properly. This drift pin is pushed through the pin hole in the yoke by the loading pin which then remains in place.

Dimensional tolerances on the yoke are not particularly critical since bending moments are reduced by specimen rotation about the hard loading pin.

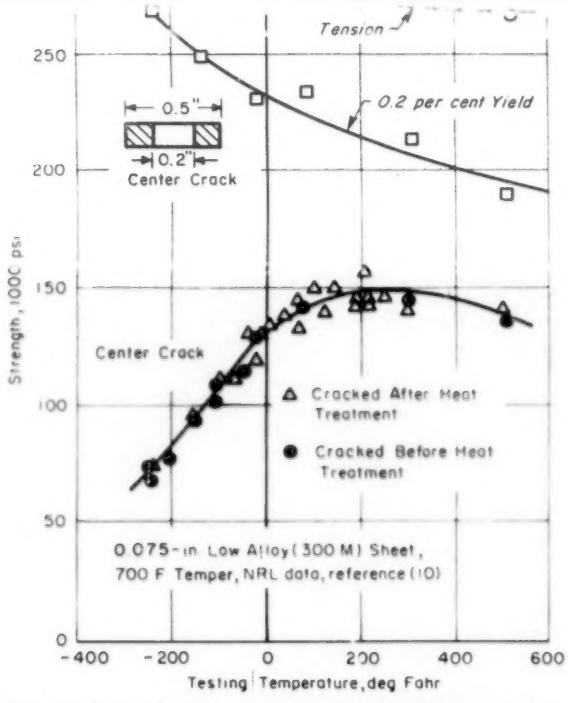

Fig. 20.—Center crack-strength as function of testing temperature for specimens fatigue-cracked before or after heat treatment.

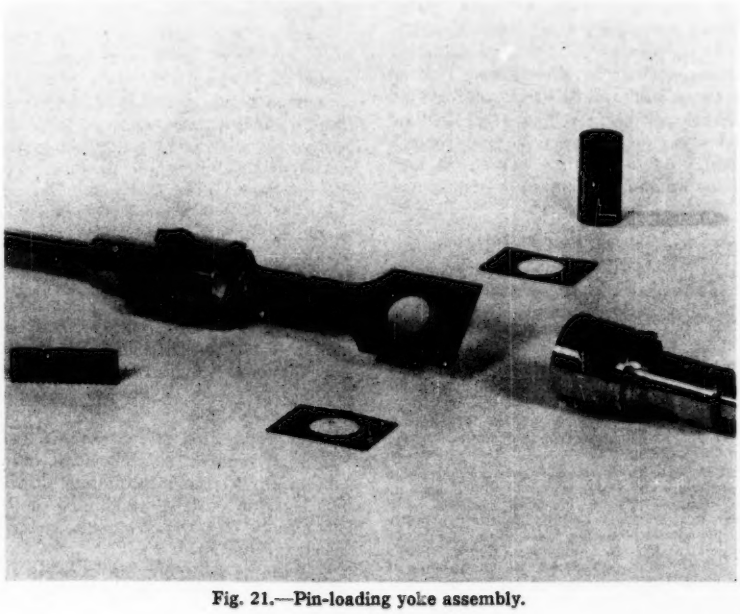

Fig. 21.—Pin-loading yoke assembly.

An Instrument for Determination of Impact Sensitivity of Materials in Contact with Liquid Oxygen[1]

By WILLIAM R. LUCAS and WILBUR A. RIEHL

An apparatus developed by the Army Ballistic Missile Agency for use in determining the impact sensitivity of materials in contact with liquid oxygen is described. The ABMA impact tester provides flexibility of testing conditions and reproducible results. Test results illustrating variables which must be controlled in impact testing are also presented.

LIQUID oxygen is one of the most important oxidizers in liquid rocket propellant systems. Pure liquid oxygen (lox) is stable and not subject to detonation by mechanical shock, but mixtures of lox with most organic materials and certain inorganic materials including aluminum, magnesium, lead, and iron oxide will explode under conditions of impact. Spontaneous combustion does not occur generally in the liquid phase because of the extremely low temperatures involved. However, under mechanical shock, detonation will occur when lox comes in contact with many elastomers and gasket materials, sealants, lubricants, threading compounds, and hydrocarbon residues on components. Aluminum valves and lines transporting lox have been observed to ignite and burn violently when struck by a hammer. Thus, it is necessary not only to certify a given product for use with lox, but that it is also necessary to test each batch of material to be used with lox. This is especially true of heterogeneous material from which some gaskets are made. For these reasons, effort was expended to develop an impact sensitivity test apparatus for use at the Army Ballistic Missile Agency (ABMA).

As materials were tested with the rather crude early testers, it became obvious that it was necessary to design an impact tester for maximum reproducibility. Some of the early instruments were more variable than the materials being tested. Impact levels for acceptability can be set arbitrarily by calibrating the instrument against a few materials known to be reasonably safe with lox. However, an instrument must usage for testing explosives, and at least two other testers have been used in qualifying materials for use with lox (2,3,4). However, the ABMA tester in current use has been used for approximately three years and has given consistent results on different types of materials such as lubricants, oils, greases, solvent residues, and gaskets.

The ABMA impact tester has been recommended by the Associate Contractors of Ramo-Wooldridge Corp., the Army Ballistic Missile Agency, and the Wright Air Development Command as the standard test equipment for determining the impact sensitivity of lubricants and sealants used in a lox environment. A test procedure involving this apparatus constitutes a part of the tentative military specification.

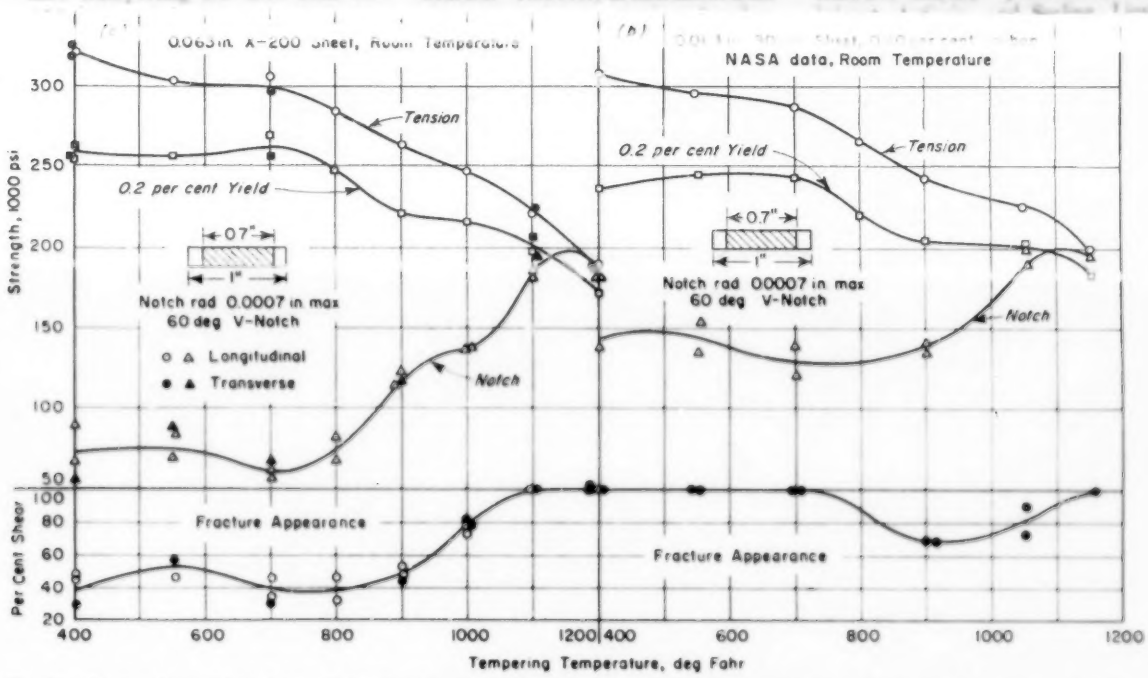

Fig. 22.—Sharp edge-notch and smooth tensile strength and fracture appearance of sharp edge-notch specimens as function of tempering temperature.

Reporting of Results

On the basis of available evidence, the nominal notch strength and a measure of fracture appearance should be reported together with the corresponding smooth ultimate and 0.2 per cent yield strength.

The notch strength is defined as:

$$\sigma_{NS} = \frac{P_{max}}{B(W - 2a_0)}$$

where P_{max} is the maximum load, B the sheet thickness, W the specimen width, and $2a_0$ the total initial notch depth. The corresponding smooth strength values should be obtained using specimens heat treated in exactly the same manner as the notch specimens. It is recommended that preferably triplicate, but at least duplicate, notch tests be made for each metal condition to be investigated.

If $\sigma_{NS} \geq \sigma_{YS}$ and $B \leq 0.063$ in., the

since $\sigma_{NS} \leq \sigma_N$ under all conditions.

It is also recommended that the ratio between the notch strength and the tensile strength, designated as the sharp edge-notch tensile-strength ratio, be reported. This quantity is equal to or slightly above the tensile strength if there has been sufficient plastic flow to eliminate the elastic stress concentrations.

Values below unity indicate various degrees of notch sensitivity or, stated differently, the inherent resistance to brittle fracture decreases with a decrease in this ratio. The screening test is no longer sensitive to embrittling factors when this ratio is unity or above.

In addition, a ratio may also be formed between the notch strength and the yield strength. This ratio is designated as the "sharp edge-notch yield-strength ratio." It has the advantage that the strength of the notch specimen is compared directly to a stress usually emphasized in design. Its disadvantage is that σ_{YS} is a purely arbitrary number defined differently by different people.

It appears that for heat-treated steels, 100 per cent shear fractures always characterize material or testing conditions producing sharp-notch strengths equal to or higher than the yield strength. Typical behavior is shown in Fig. 22(*a*) for X-200 steel, tempered at various temperatures and tested at room temperature. However, 100 per cent shear is a necessary but not sufficient condition for high fracture toughness. For example, alloy 300M with 0.40 per cent carbon exhibits 100 per cent shear at tempering temperatures below about 700 F with sharp-notch strengths well below the yield strength (Fig. 22(*b*)).

Instrumented Bend Test

The instrumented bend test[10] is a crack-propagation test wherein a small unnotched rectangular specimen is biaxially stressed to failure by bending as a simple beam under three-point loading. This test provides a crack-propagation-resistance parameter that correlates with other types of crack-propagation tests and with pressure-vessel behavior.

[10] Developed by Allison Division, General Motors Corp.

Description of Test

Test Specimen.—Most of the instrumented-bend-test data have been obtained using a specimen 0.052 by 0.700 by 1.5 in. These dimensions were chosen for two reasons:

1. A specimen of this size can easily be obtained from subscale as well as full-scale rocket motor cases after burst testing.
2. The width-to-thickness ratio of approximately 14 provides an adequate 2:1 biaxial stress area approximately $\frac{1}{2}$ in. in width.

Specimens of other thickness and width may be used, but a minimum width-to-thickness ratio of 10 is recommended. The width and thickness should remain constant when results of different materials or processes are compared.

All specimens are ground to the finished dimension without breaking sharp edges. The surface finish is not critical—as long as grinding burns are avoided—with the normal surface finish ranging from 10 to 20 rms. Surface finishes ranging from 10 to 150 rms do not essentially change the test results. No mechanical notches or cracks of any kind are necessary in the preparation of these test specimens.

Equipment and Instrumentation.—Basically, the test consists of bending the specimen as a simple uniform rectangular beam supported at two points by $\frac{1}{4}$-in. rounds and loaded through a $\frac{1}{8}$-in. round at the center of a 1-in. span, as shown schematically in Fig. 23.

All components of the bend test fixture are made from tool steel, hardened and tempered to Rockwell hardness C 60. The rate of deflection is maintained constant in a tension testing machine with a crosshead speed of 0.5 in. per min. This value is not critical within the range of 0.5 to 2.00 in. per min. The load on the specimen is sensed during the test by a resistance strain gage load cell (1000 lb capacity) placed between the bend test fixture and the lower platen of the tension testing machine. The output of the load cell is fed into a strain-gage amplifier and recorder. The recorder must have sufficient pen speed response to track the load on the specimen accurately without lag. An oscillographic type recorder with a frequency response of 60 cps or higher is recommended. The strain gage load cell and the recorder are calibrated against the tension testing machine so that each division of the recorder strip chart is usually equivalent to 20 or 25 lb of load. The chart paper is usually driven at 5 mm per sec. The strip chart of the recorder thus furnishes a continuous record of the specimen load as a function of time during the test.

Interpretation and Calculation of Test Results

Typical load-time curves obtained from instrumented bend tests conducted on a high-strength steel, heat treated to uniaxial 0.2 per cent yield strength levels of 245,000 psi (SN 5) and 197,000 (SN 4), are shown in Fig. 24.

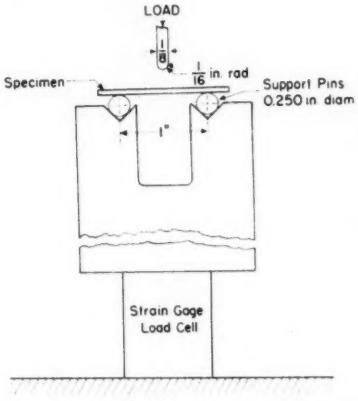

Fig. 23.—Schematic representation of instrumented bend test.

Both curves show the same general behavior: The load increases to maximum value, then decreases at a relatively slow rate until a lower load is reached at which time there is a very rapid change in the rate of unloading. The maximum load is indicated by P_m, and the load at which the rapid change in rate of unloading begins is denoted by P_1.

Observation of the tension face of specimens during the test has shown that the first cracks appear in the center biaxially stressed area at the P_m load and progress by slow crack propagation until P_1 load is reached, when rapid crack propagation occurs. Figure 25 shows ink-stained fractures demonstrating slow crack progression as the load decreases from P_m to P_1.

The first step in the calculation of the instrumented bend test parameter is to pick P_m and P_1 from load-time curves. A sharp change in the shape of the load-time curve is required to accurately pick P_1. When materials approach low strength levels, the P_1 point is not distinct, and reliable parameter calculations cannot be made. These loads are

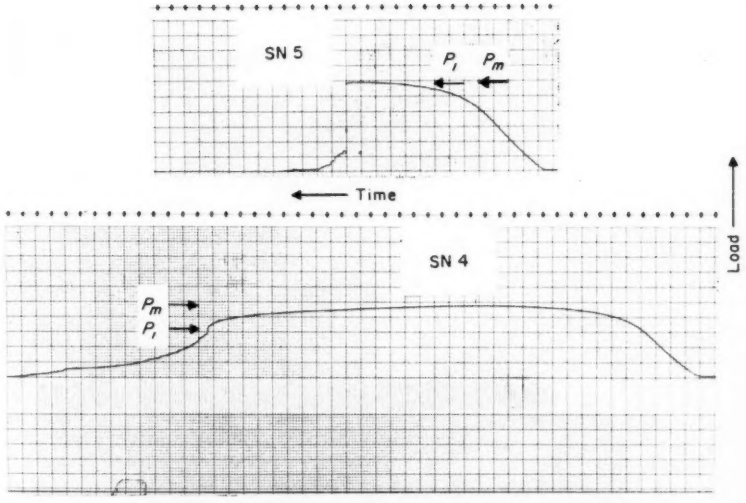

Fig. 24.—Recording charts for instrumented bend test.

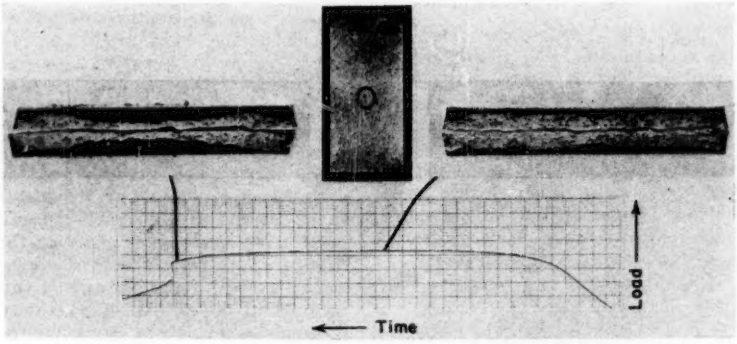

Fig. 25.—Crack propagation in instrumented bend test.

TABLE VI.—TEST RESULTS FOR H-11 STEEL SHEET.

Specimen	Tempering Temperature, deg Fahr	Rockwell Hardness, C-scale	Instrumented Bend Test, $\sigma_m - \sigma_1 \times 10^{-3}$, psi	Center-Crack Tension Test (Specimen 0.095 in. Thick)				Uniaxial Tension Test		
				K_c, psi/$\sqrt{\text{in.}}$	Per Cent Shear	Net Fracture Stress, psi	Net-Fracture Stress/σ_y	σ_y, 0.2 per cent Yield Stress, psi	Ultimate Tensile Strength, psi	Elongation in 2 in., per cent
V6-1	600	53-54	0.33	89 000	50	136 000	0.59	230 000	296 000	8.5
2	600	53-54	0.22	61 500	44	133 000	0.58	232 000	296 000	8.5
3	600	53-54	0.25	74 500	48	133 500	0.58	230 000	293 000	8.2
4	600	53-54	0.47	67 000	56	135 000	0.59	...	...	...
5	600	53-54	0.40	90 000	56	140 500	0.61	...	...	...
6	600	53-54	0.48	61 500	48	147 000	0.64	...	...	...
V8-1	800	53-54	0.22	31 500	26	85 000	0.36	242 000	290 000	12.1
2	800	53-54	0.07	...	...	...	...	240 000	291 000	11.3
3	800	53-54	0.11	...	23	93 000	0.39	...	...	...
4	800	53-54	0.07	35 000	20	81 500	0.34	...	...	...
5	800	53-54	0.18	32 000	22	90 000	0.37	...	...	...
6	800	53-54	0.15	26 700	17	63 600	0.26	...	...	...
V10-1	1000	54-55	0.04	26 800	0	75 500	0.31	236 000	304 000	8.9
2	1000	54-55	0.14	18 000	0	61 800	0.26	244 000	310 000	8.3
3	1000	54-55	0.04	19 300	0	60 900	0.25	...	...	...
4	1000	54-55	0.07	20 700	0	61 800	0.26	...	...	...
5	1000	54-55	0.07	17 500	0	56 000	0.23	...	...	...
6	1000	54-55	0.11	...	...	...	...	...	...	...
V11-1	1100	46-47	0.94	110 000	100	206 000	1.02	205 000	236 000	10.6
2	1100	46-47	0.92	104 000	100	198 000	0.98	202 000	233 000	10.4
3	1100	46-47	0.83	98 000	100	204 000	1.00	200 000	235 000	10.6
4	1100	46-47	0.95	97 000	100	201 000	0.99	...	...	...
5	1100	46-47	...	117 000	100	198 000	0.98	...	...	...
6	1100	46-47	1.02	114 000	100	204 000	1.00	...	...	...

corrected for small dimensional differences in the thickness and width of different samples by converting to maximum outer fiber stress, σ_m and σ_1, by means of the beam formula:

$$\sigma = \frac{3PL}{2wt^2}$$

where:

σ = maximum outer fiber stress, psi,
P = load, lb,
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t = thickness of specimen (0.052 in. nominal), and
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The difference between σ_m and σ_1 then represents the reduction in the calculated highly localized outer fiber stress in the specimen due to slow crack progression before rapid crack progression occurs. The instrumented bend test parameter is defined as $\sigma_m - \sigma_1$. The values calculated from the two curves in Fig. 24 were 0.26×10^5 psi for SN 5 and 1.45×10^5 psi for SN 4.

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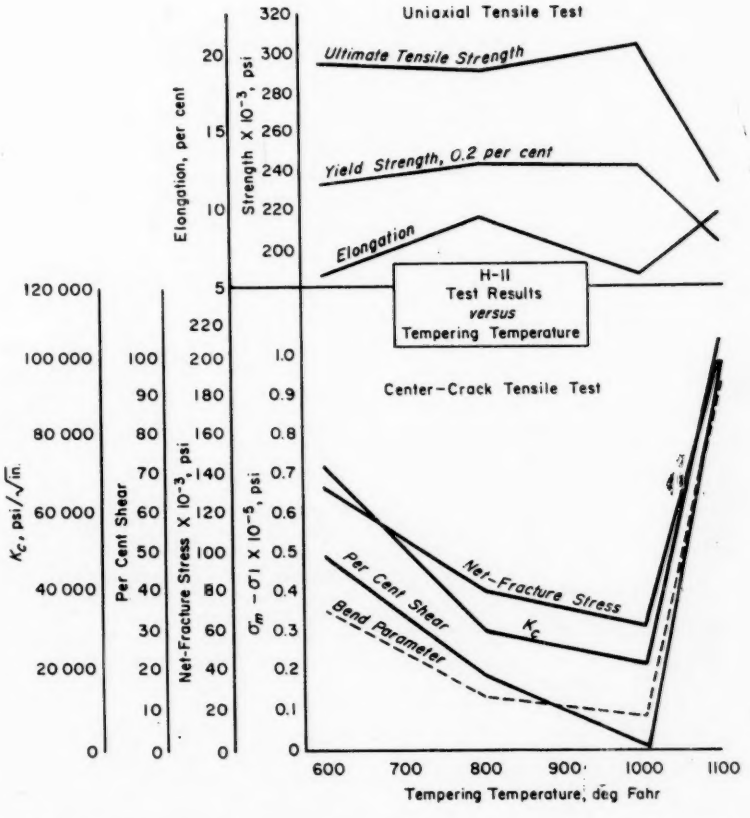

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Actions on Standards

THE ADMINISTRATIVE COMMITTEE ON STANDARDS is empowered to pass on proposed new tentatives and revisions of existing tentatives, and tentative revisions of standards, as well as withdrawals of standards and tentatives offered between Annual Meetings of the Society. On December 28, 1959, the Standards Committee took the following actions. Anyone interested in securing copies of the standards should write to Headquarters regarding their availability.

Glass

Standard Methods of Test for Resistance of Glass Containers to Chemical Attack (C 225 – 54)

Revised and Reverted to Tentative.—Through use of the methods, Committee C-14 became aware of the need for various changes in order to secure concordant results between laboratories. The revised methods are now identical to the standard for this same determination that appears in the new issue of the *U. S. Pharmacopoeia*.

Electrical Insulating Materials

Tentative Methods of Test for A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials (D 150 – 54 T).

Revision.—A new Appendix III covering Air-Gap and Liquid Displacement Measurement Techniques has been added.

Tentative Methods of Testing Fully Cured Silicone Rubber Coated Glass Fabric and Tapes for Electrical Insulation (D 1458 – 57 T).

Revision.—The instructions for thickness measurements have been clarified and made more specific.

Shipping Containers

Standard Methods of Test for Water Vapor Permeability of Shipping Containers (D 1008 – 51).

Revised and Reverted to Tentative.—Round-robin tests indicated the need for certain refinements in the method in order to improve interpretation of requirements and reproducibility of results.

Rubber

Tentative Specification for Ozone Resisting Butyl Rubber Insulation for Wire and Cable (D 1352 – 54 T)

Revision.—The specification has been brought up to date with current practice. The revised specification will more accurately define the quality of ozone resisting butyl insulation being produced.

Plastics

Tentative Method of Test for Tensile Properties of Plastics: Microtensile Specimens (D 1708 – 59 T)

New Tentative.—The method is intended for use in determining the comparative tensile strength and elongation properties of plastics in the form of standard test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing-machine speed. It can be used for specimens of any thickness up to $\frac{1}{8}$ in., including thin films, and is designed specifically for use where only limited amounts of material are available. Where sufficient material is available, the Test for Tensile Properties of Thin Plastic Sheets and Films (D 882), or the Test for Tensile Properties of Plastics (D 638) shall be used.

Tentative Method of Test for Impact Resistance of Polethylene Film by the Free Falling Dart Method (D 1709–59 T)

New Tentative.—This method describes a procedure for determining the energy at which polyethylene film exhibits fracture under specified conditions of impact, such as sample geometry, dart head dimensions, velocity.

Tentative Method of Test for Water Absorption of Plastics (D 570 – 59 T)

Revision.—In Section 6(*a*) covering 24-hr immersion, change "At the end of 24 ± 1 hr" to read "At the end of 24 (plus $\frac{1}{2}$, minus 0 hr.)"

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By WILLIAM R. LUCAS and WILBUR A. RIEHL

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The Ordnance Safety Manual precludes the use of organic material with lox (1).[2] Of course, this is impractical in missile systems.

The need for impact sensitivity test apparatus for use in classifying materials as to degree of hazard—thereby providing a means of qualifying materials for use with lox—became apparent to Engineering Materials personnel at the Army Ballistic Missile Agency very early in the development of missiles utilizing liquid propellants.

This need was intensified by the realization that it is not sufficient to certify a given product for use with lox, but that it is also necessary to test each batch of material to be used with lox. This is especially true of heterogeneous material from which some gaskets are made. For these reasons, effort was expended to develop an impact sensitivity test apparatus for use at the Army Ballistic Missile Agency (ABMA).

As materials were tested with the rather crude early testers, it became obvious that it was necessary to design an impact tester for maximum reproducibility. Some of the early instruments were more variable than the materials being tested. Impact levels for acceptability can be set arbitrarily by calibrating the instrument against a few materials known to be reasonably safe with lox. However, an instrument must give reproducible results day after day, and two or more instruments of the same design must give reproducible results. With these considerations in mind, the instrument described herein was developed.

The tester described represents the third refinement of the ABMA impact tester. Impact testers are in common usage for testing explosives, and at least two other testers have been used in qualifying materials for use with lox (2,3,4). However, the ABMA tester in current use has been used for approximately three years and has given consistent results on different types of materials such as lubricants, oils, greases, solvent residues, and gaskets.

The ABMA impact tester has been recommended by the Associate Contractors of Ramo-Wooldridge Corp., the Army Ballistic Missile Agency, and the Wright Air Development Command as the standard test equipment for determining the impact sensitivity of lubricants and sealants used in a lox environment. A test procedure involving this apparatus constitutes a part of the tentative military specification, "Lubricant, Antiseize and Sealing, Liquid Oxygen Systems," which is patterned after the comparable specification approved by the Air Force and the Navy Bureau of Aeronautics, Military Specification MIL-T-5542B (ASG), "Thread Compounds, Antiseize and Sealing, Oxygen Systems," applicable to gaseous oxygen systems.

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WILBUR A. RIEHL is chief of the General Chemistry Section of Army Ballistic Missile Agency, Redstone Arsenal, Ala. He received a B.S. from Tulane Univ. in 1947 and an M.S. in chemistry from Louisiana State Univ. in 1950. In addition, he has studied at the University of Alabama, Cornell Univ., and University of California at Los Angeles.

Since 1951 he has been working in the field of chemistry of missiles and rockets. Much of this work has been devoted to studies on the chemical compatibility of engineering materials with liquid rocket propellants.

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[1] This paper was presented at the Third Conference on the Design of Experiments in Army Research, Development, and Testing, Washington, D. C., Oct. 16–18, 1957.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper.

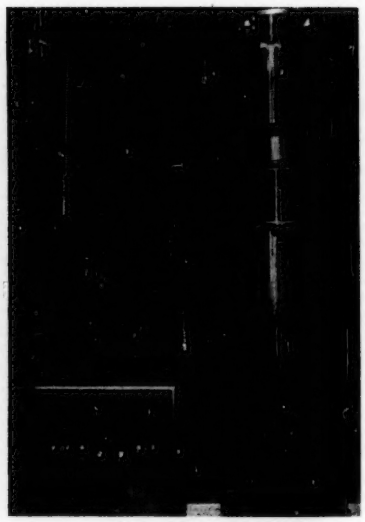

Fig. 1.—Impact tester.

Recently, the instrument has been used for determining impact sensitivity of materials in concentrated hydrogen peroxide.

Description of ABMA Impact Tester

The ABMA tester is designed to allow a plummet to approximate free fall as nearly as possible. This plummet lands upon the top of a striker pin, the bottom of which is immersed in lox and in contact with the specimen under test. By this means, the energy is transferred from the falling plummet to the specimen with a minimum of splashing of the lox.

The basic instrument as shown in Figs. 1 and 2 consists of a plummet guided in its vertical fall by two sets of ball bearings, one set at each end of the plummet. The bearings, arranged at the vertices of equilateral triangles, roll freely in tracks milled in 1 by 1 by 72-in. stainless steel bars. These tracks are bolted rigidly to unistrut members and are accurately aligned with shims so that even contact with the ball bearings is maintained at all points along the length of the track. The unistrut supports are securely anchored to the top and base plates. The base plate is mounted with leveling screws to a steel frame of table height. The frame, in turn, is secured to the concrete floor.

As shown in Fig. 3, the control panel is separated from the instrument by a barricade containing an observation window arranged so that the operator has a view of the sample cup. The test cell is lined with acoustical tile and is darkened during a test to facilitate observation of sparks or a flash.

The plummet is held at the desired height by an electromagnet, supplemented by a spring-loaded safety catch in positive action at all times except when current is delivered to the solenoid

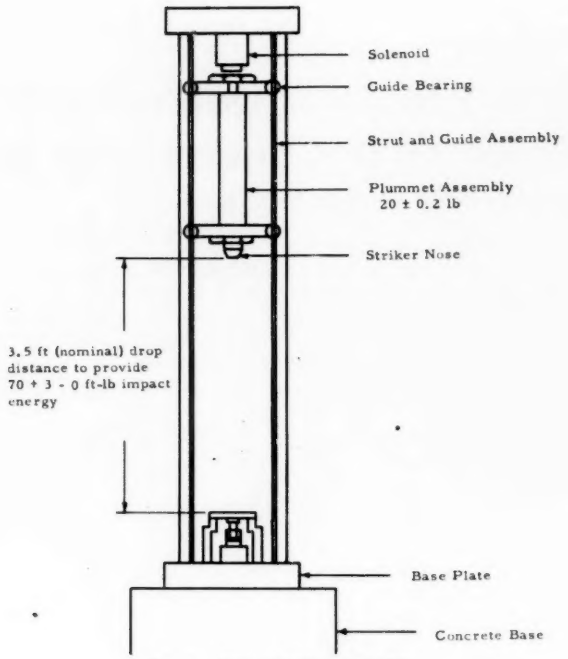

Fig. 2.—Impact tester assembly.

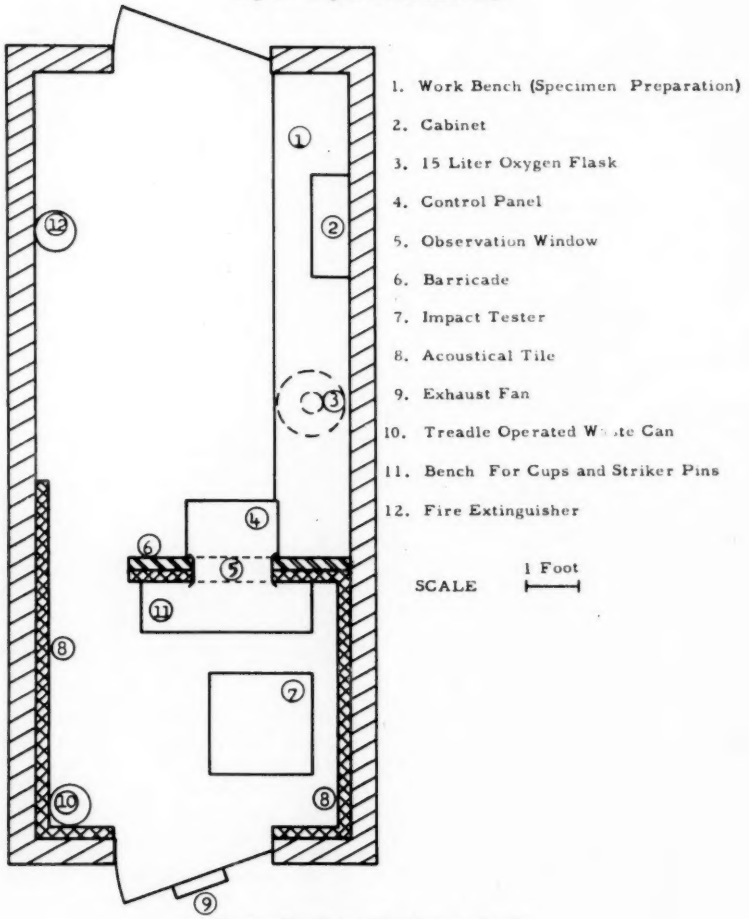

Fig. 3.—Liquid oxygen impact test cell.

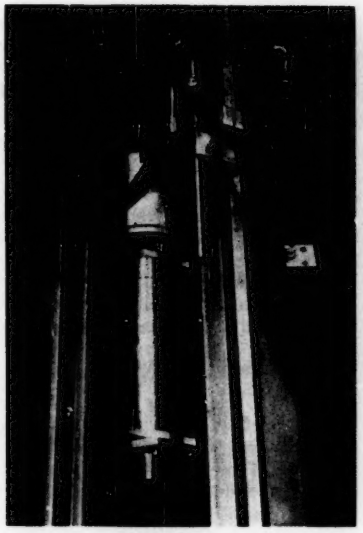

Fig. 4.—Impact tester plummet release mechanism.

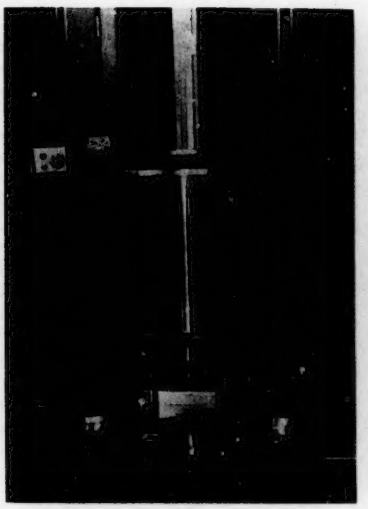

Fig. 5.—Plummet in impact position.

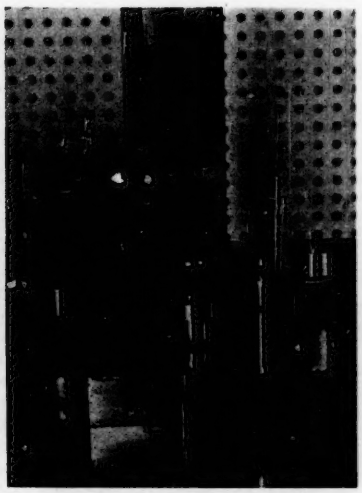

Fig. 6.—Striker pin and sample cup assembly.

activating the release of the safety catch. Figure 4 shows the electromagnet and the suspended plummet. The electromagnet may be positioned at any height from 0 to 127 cm and the total effective drop distance may be read directly from calibrations on the electromagnet support shaft.

Located on the electromagnet support and to the left of the locking handle is the height indicator. This must be reset to read 0 cm with the plummet resting on a striker pin each time a change is made in plummets or sample cup holder assemblies. Then the drop distance of the plummet can be read directly at any electromagnet setting.

Two plummets are used, one weighing 9.04 kg and the other weighing 3.4 kg. These provide operating ranges of 0 to approximately 11 kg-m and 0 to approximately 4 kg-m, respectively. The plummet having the range best suited to the sensitivity of the material under investigation is chosen.

The plummet is released by simultaneously depressing two buttons on the control panel: one button releases the safety catch and the second reverses the field of the electromagnet so that it will release as the polarity nears zero. The plummet delivers the impact to a stainless steel striker pin resting on the specimen and immersed in lox. The striker pin is 2 in. long and $\frac{1}{2}$ in. in diameter. Figure 5 shows the plummet in the impact position. As indicated in Fig. 6, the striker pin is held in position by a stainless steel collar, sliding on two guide pins mounted in the base plate. The stainless steel sample cup holder is held to the base plate by spring clamps.

This cup holder is interchangeable with a liquid nitrogen moat, serving the same function but permitting cooling of the specimen below the boiling point of lox. The moat consists of a stainless steel box to which liquid nitrogen may be added manually by pouring or by attaching the moat directly to a 50-liter Dewar flask and transferring by pressure as required. The moat was designed primarily to conserve lox. However the safety hazard introduced by condensation of atmospheric oxygen into the liquid nitrogen and on the surroundings is not justified by the advantage gained. Thus the moat is very seldom used.

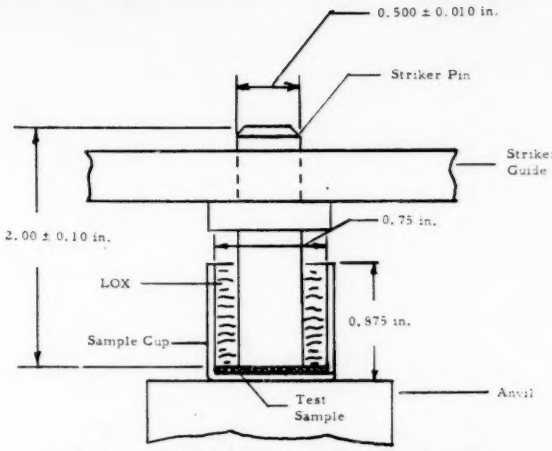

Fig. 7.—Details of striker, sample cup, and sample.

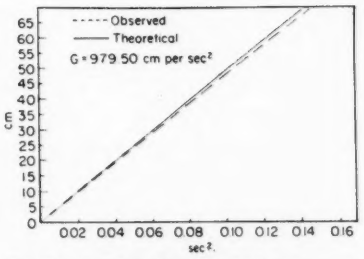

Fig. 8.—Acceleration of 9.04-kg plummet on ABMA impact tester (distance = $\frac{1}{2}g$ × sec²).

Figure 7 shows details and orientation of striker pins, sample cup, and specimen. The sample cups are stamped from commercially pure aluminum and are expendable.

The Universal Counter, shown in Fig. 1, is used to measure the time interval as the plummet drops between fixed points and thus to evaluate friction loss.

Figure 8 is a comparison of theoretical acceleration of the ABMA impact tester plummet and the measured acceleration on the properly aligned instrument. As shown in this figure, frictional loss is slight and can be considered negligible. This test should be repeated periodically as a check of the tester.

Procedure for Impact Testing

The nature of the specimen determines the manner in which it is prepared for testing. Solids are cut into disks

smaller in diameter than the inside dimension of the sample cup and greater in diameter than the striker pin. Specimens are cut without cutting oil or other coolant and are brushed free of dust or fragments prior to testing. Single pieces of gaskets are tested in order to parallel the normal gasket environment. Oils, greases, and sealing compounds are tested as smears in the bottom of the test cup.

It is imperative that the instrument, its accessories, and the room in which the tests are accomplished—especially the ceiling—be clean. Where lubricants, oils, or other materials that may splash upon impact are tested, the tester must be cleaned between tests on different materials by scrubbing with steel wool and rinsing with a pure, chlorinated hydrocarbon solvent. This includes the base plate, guide tracks, and plummet nose. The base plate may be covered with aluminum foil during test to simplify cleaning.

A clean striker pin is used for each test; thus several clean pins are necessary for a series of tests. The face of the striker must be free of pits and scratches. The pin is cleaned by vapor degreasing and alkaline cleaner soak, followed by thorough rinsing.

A test cup is used only once and discarded. Prior to its use, it is cleaned by scrubbing in detergent, rinsing with water, and finally rinsing with pure, distilled chlorinated hyrocarbon solvent.

After cleaning, the sample cup and striker pin are never handled by hand; and such equipment as forceps, tongs, and sample trays are cleaned in the same manner as the sample cups.

Striker pins are precooled to lox temperature by suspending on a clean, stainless steel wire in a Dewar flask of lox. Specimens and cups are precooled by immersion in a separate container of lox for each specimen. The cup is filled with lox before transferring to the tester and topped with lox just prior to impact. It is important that the time lapse between lox topping and impact be held to a minimum.

Specimens are tested at a given impact level, and this level reduced until in 20 consecutive tests there is no evidence of sensitivity. Sensitivity is indicated by an audible report or a flash visible in the darkened room or evidence of burning visible upon postexamination of the cup. The level at which there is no evidence of sensitivity in 20 consecutive tests is called the level of lox impact insensitivity.

In the early days of testing, the insensitivity level of material tested was established on the basis of 10 consecutive tests. However, there have been cases where there were no detonations in the first 10 trials but one or more detonations in the second 10 trials. In a consideration of 1760 individual tests, it was shown that with duplicate tests, one can expect the number of detonations in the first set of 10 to agree within ± 1.5 of the number of detonations in the second set of 10 trials two out of three times. In several series of 20 duplicate tests the number of detonations in the first 20 trials agreed with ± 1.5 detonations of the number in the second 20 two out of three times. Obviously, with the greater number of tests, the reproducibility of results is increased; however, it seems impractical to make more than 20 consecutive tests at one impact level on a given material.

An acceptable impact level cannot be established which would be applicable to all materials. Where the anticipated impact in use is known, this level with a safety factor is established as the acceptable test level. In most cases, the environment cannot be evaluated quantitatively, and it is necessary to select as the standard the impact sensitivity level of a material which has been used successfully. For example, Oxyseal, a commercial sealant consisting primarily of a mixture of graphite and a chlorinated biphenyl, has been used in rocket engines for several years on valves, pipe fittings, and similar parts in lox service. Since the experience of several agencies using this material has been favorable, and no explosion has been traceable to it, this material has constituted a standard against which to check other sealants.

Test Results

Inasmuch as more work has been done recently on lubricants and sealants than on other materials, test results from these types of material will be discussed briefly in order to identify testing variables which must be controlled.

Effect of Specimen Thickness

A series of tests was made in order to show the effect of specimen thickness on test results. Some of the results are shown in Table I. From this table, it is seen that reducing the specimen thickness, with all other factors being constant, increased sensitivity by 16 times. In another test of a proprietary sealant at 7 kg-m energy, there was one detonation in 20 trials using a specimen thickness of 0.050 in.; under the same conditions except with a specimen thickness of 0.004 in. there were 19 detonations in 20 trials. The thickness of the specimen can be checked easily by weighing

TABLE I.—EFFECT OF SAMPLE THICKNESS OF A PROPRIETARY SEALANT ON LOX IMPACT SENSITIVITY.

Impact Energy	Number of Detonations Using Specimen Thickness of 0.050 in.	Number of Detonations Using Specimen Thickness of 0.004 in.	Increase in Sensitivity for 0.004-in. Specimen
4 kg-m (9.04 kg plummet)	1/40[a]	8/20	16 times
4 kg-m (3.4 kg plummet)	2/40	16/20	16 times
10 kg-m	4/40	29/40	7.25 times

[a] 1/40 indicates 1 detonation in 40 trials.

TABLE II.—EFFECT OF PLUMMET MASS ON LOX IMPACT TEST RESULTS

Material	Impact Energy kg-m	Detonations		Increase in Sensitivity
		9.04-kg Plummet	3.4-kg Plummet	
Proprietary sealant number 1, 0.050 in. thick	4	1/40[a]	2/40	2 times
Proprietary sealant number 1, 0.004 in. thick	4	8/20	16/20	2 times
Proprietary sealant number 1, 0.050 in. thick	3.5	1/20	5/10	10 times
Proprietary sealant number 1, 0.050 in. thick	2.5	2/20	4/10	4 times
Proprietary sealant number 2, 0.004 in. thick	4.0	0/20	1/20	. . .

[a] 1/40 indicates 1 detonation in 40 tests.

TABLE III.—EFFECT OF DIAMETER OF STRIKER FACE ON LOX IMPACT TEST RESULTS USING THE ABMA TESTER.

Gasket Material	Insensitivity Level, kg-m		Increase in Insensitivity Level
	½-in. Diameter Striker Face	¾-in. Diameter Striker Face	
Allpax 5364A	5	9	1.8 times
Allpax 5408A	5	10	2 times
Allpax 5408B	5	9.5	1.9 times
Allpax 5409B	5	9.5	1.9 times
Allpax 7700	4.5	7	1.6 times
Allpax 9662	4.5	9.5	2.1 times
Allpax 9670	5	10	2 times
Johns-Manville 76	4.5	9	2 times
Johns-Manville 60	3	8	2.7 times

the sample cup before and after addition of the specimen and then calculating the depth, knowing the density of the material being evaluated.

Since the purpose of the impact tester is to qualify a material for use with lox, it seems desirable to select a test condition which is most sensitive to variations in materials. In this case, the thicker specimen seems to provide the better results. With the thin specimen the spread between an acceptable material, Oxyseal, and an unacceptable material, Proprietary Sealant No. 1, is only 2 kg-m; the spread using a thick specimen is approximately 8 kg-m.

Effect of Plummet Mass

The effect of the plummet mass on test results was observed. In one case, a plummet weighing 9.04 kg was used to provide a given impact energy; in the other case, a plummet weighing 3.4 kg was used to provide the same impact energy. Results of this series of tests are presented in Table II. As can be seen from this table, the lighter plummet indicated a higher order of sensitivity as expected.

Effect of Striker Pin Diameter

In the ABMA tester, the diameter of the striker pin is $\frac{1}{2}$ in. The effect of varying this diameter when testing gasket materials is shown in Table III. It is shown that the insensitivity level varies for the most part directly with the diameter of striker pin face. There is not a direct correlation between impact insensitivity of lubricants and area of impact; however, the importance of using a constant impact area is established.

Effect of Cleaning Techniques

The effect of cleaning techniques for sample cup and striker were investigated and results are shown in Table IV. The first method shown is the standard practice. Thus, it is evident from these results that much care must be given to cleaning and handling the specimen. By placing a few particles of sand, Alundum, or carborundum as fine as 320 mesh in a sample cup with lox, the aluminum cup was made to react explosively under impact in 50 per cent or more of the trials. This emphasizes further the importance of cleaning.

Sensitivity Characteristics

In order to show the manner in which sensitivity decreases toward a level of insensitivity, data on a series of representative specimens are shown in Figs. 9, 10, 11, and 12. From these results, which show that in some cases a wide range exists between 100 per cent and 0 per cent activity, it appears dangerous to establish an acceptability level of impact which allows any detonations in 20 trials. Therefore, acceptance levels are established at impact energies at which no detonations are experienced.

A variety of materials applicable to the oxidizer systems of missiles have been tested with the instrument described herein. On the one hand are the comparatively insensitive materials such as Teflon, Kel-F, and fluorolube; on the other hand are the very sensitive materials such as leather, epoxy resins, hydraulic oils, some commercial sealants, and hydrocarbon residues from cleaning solvents. The response of the various sensitive materials to impact varies widely. Using a specimen of approximately 0.5 g there is, in some cases, a loud report accompanied by a flash. Often the surface of the aluminum cup is melted. In other cases, there is only a flash. Slight charring is the only evidence of impact in some of the less sensitive materials.

TABLE IV.—EFFECT OF CLEANING TECHNIQUES ON LOX IMPACT SENSITIVITY[a]

Cleaning Techniques		Detonations in 40 Tests
Cup	Striker Pin	
Detergent,[b] H_2O rinse, CCl_4 rinse	Vapor degrease, alkaline clean	0
Vapor degrease, alkaline clean.	Vapor degrease, alkaline clean	2
Detergent, H_2O rinse, CCl_4 rinse	Vapor degrease, CCl_4 scrub	4
Detergent, H_2O rinse, CCl_4 rinse	Steel wool, Vythene	6

[a] Impact of 10 kg-m through a striker of ½-in diameter face in sample cup filled with lox.
[b] Sorapon SF.

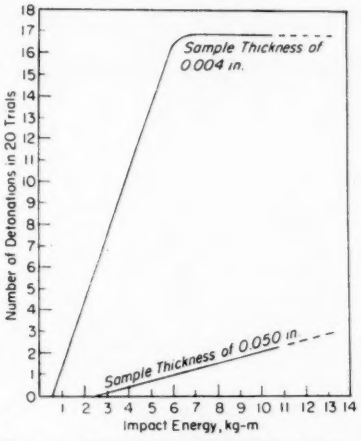

Fig. 9.—Lox energy sensitivity of proprietary sealant No. 1.

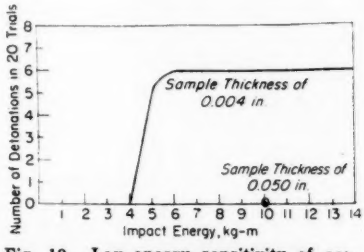

Fig. 10.—Lox energy sensitivity of proprietary sealant No. 2.

Conclusions

One of the most important considerations for selecting materials to be used with liquid oxygen (lox) is impact sensitivity. For this reason, a test apparatus was developed for determining the impact sensitivity of materials in lox. This apparatus, designated the ABMA impact tester, has the following advantages over other known instruments designed for the same purpose:

1. It provides reproducible results. Reproducibility of test results is the chief feature desired in an instrument of this type. It is believed that other instruments built according to the plans

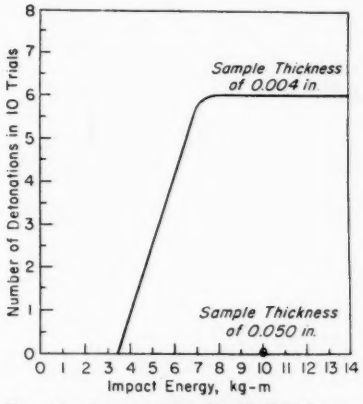

Fig. 11.—Lox energy sensitivity of proprietary sealant No. 3.

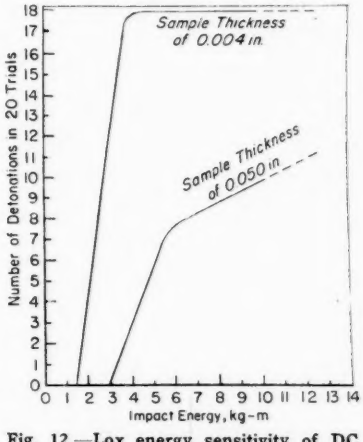

Fig. 12.—Lox energy sensitivity of DC high vacuum grease.

for the ABMA impact tester and used according to the standard operating procedure will provide the same results.

2. The low friction loss of the falling plummet approaches, in effect, a free falling body.

3. The striker pin is immersed in lox and in contact with the specimen at the time of impact. This reduces splash encountered when the nose of the plummet hits the striker.

4. It utilizes cheap, expendable sample cups.

5. By using expendable sample cups and a clean striker pin for each test, both impact surfaces are fresh for each test.

6. It provides flexibility of testing conditions to accommodate widely varying material.

7. It provides adequate safety features.

Acknowledgment

The authors are indebted to the Army Ballistic Missile Agency for permission to publish this study, and to Messrs. R. F. Hurst (deceased), J. A. Lucas, T. J. Carter, and D. G. Price for their assistance in the experimental work.

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High Temperature Vacuum Equipment for Treatment of Reactive and Refractory Metals

By A. L. FEILD, JR. and V. A. PECKHAM, JR.

Equipment design considerations for the elevated-temperature treatment of reactive and refractory metals in a high-vacuum environment are discussed, and present limitations of several types of research and development equipment are reviewed. New designs for a vacuum hot hardness tester, vacuum quenching furnace, and vacuum tension test furnace are presented. These units are capable of operation to 3000, 4000, and 3000 F respectively, and provisions can be made to extend further the upper temperature limit. Also, the design features of an operable inert atmosphere rolling mill for processing refractory metals without contamination at temperatures to 3500 F are revealed.

Metals such as titanium, zirconium, columbium, tantalum, molybdenum, and tungsten have assumed commercial importance within the last decade as materials for specialized metallurgical applications where high strength, superior corrosion resistance, or high melting point are necessary. The unique advantages of the various reactive metals—titanium and zirconium—and refractory metals—columbium, tantalum, molybdenum, and tunsten—and their alloys have been well publicized. However, advantages in finished products are accompanied by problems in production, mill processing, and testing which have not been completely solved to date. Most operations involved in these three areas require the use of vacuum or inert atmosphere because of the chemical activity of the transition series elements involved. Because of the high melting points of the materials, generally above 3000 F, the production of extremely high temperatures in an inert environment is a necessity. These factors pose many problems in the design, construction, and operation of equipment which will perform satisfactorily under rigorous conditions. With the continuing development of new and improved alloys, the need for producing ever higher temperatures has become pressing, and earlier designs of equipment have proven inadequate.

The purpose of this paper is to describe several satisfactory items of equipment for high-vacuum work at elevated temperature which have been designed and built by the authors.

Design Considerations

The attainment of high temperatures for metal treatment in high vacuum in the solid state without undesirable contamination from the atmosphere or from equipment components has been a field of increasing importance. Early workers designed and constructed their own equipment since there were no commercial units that could be purchased to meet exacting requirements. Two basic types of heating systems used

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A. L. FEILD, JR., research associate with the Universal-Cyclops Steel Corp., has been engaged in research and development on reactive and refractory metals since 1951. This work has involved considerable design and construction of specialized equipment for melting, fabrication, and testing of these specialty metals. At present, he is concerned with various development aspects of pure and alloyed molybdenum, columbium, tantalum, and tungsten.

V. A. PECKHAM, JR., research assistant, has been employed in the Universal-Cyclops Research Department since his graduation from the University of Michigan in 1956. His primary work has been concerned with the design of high temperature furnaces and mechanical equipment for operation within evacuated enclosures.

have been of the induction or radiant resistance type. Induction heating has the advantages of rapid heating and capability of reaching very high temperatures. Its disadvantages include the inability to control temperatures closely, the outgassing problems associated with the use of ceramic materials in furnace construction, coil arcing in high vacuum with heavy power loads, and the initially high installation cost for the equipment. Radiant resistance heating has advantages of close temperature control if proper regulation systems are used, lower installation cost, and fewer outgassing propensities if metallic systems are employed. Disadvantages have been slow heating of the work, especially in larger sections, and the inability to reach extremely high temperatures because of inadequate chamber design.

Recently, those engaged in high-temperature high-vacuum work have realized that system interiors must be built entirely of metal components of high melting point which are adequately water cooled and which replace conventional refractory ceramics and graphite. Only in this way can a system be made capable of producing a consistent high vacuum in the low-micron range at temperatures up to 5000 F. The use of molybdenum, tantalum, and tungsten have now become fairly common for these applications, both in resistance heating as elements and in induction heating as susceptors.

The following descriptions of equipment are to acquaint those who may be contemplating design or purchase of such apparatus with the fundamental concepts of operable equipment design. Each of the units described has been designed, built and operated.

Equipment Design and Operation

Vacuum Hot-Hardness Tester

Hot-hardness testing is a useful tool for screening alloy compositions at high temperatures without resorting to expensive and time-consuming stress-rupture and tensile tests. There is a rough correlation between the hardness of a metal or alloy at elevated temperature and its corresponding ability to resist rupture or excessive creep under applied loads at that temperature. By subjecting samples of a material to hardness testing through a complete range of temperatures, both in heating and cooling, it is possible to ascertain quickly whether the composition has merit for projected usage at such temperatures. Promising materials can then be fully evaluated by conventional high-temperature tests and unsuitable ones can be discarded immediately.

Hot-hardness testers have been constructed in various laboratories, and several have been well described (1,2).[1] The purpose of the modified design here discussed is to eliminate the necessity of an inert atmosphere, to remove refractory oxides from the evacuated system, and to load internally the indenter and obviate the use of bellows or a friction-type external sliding vacuum seal. The apparatus is illustrated in Fig. 1.

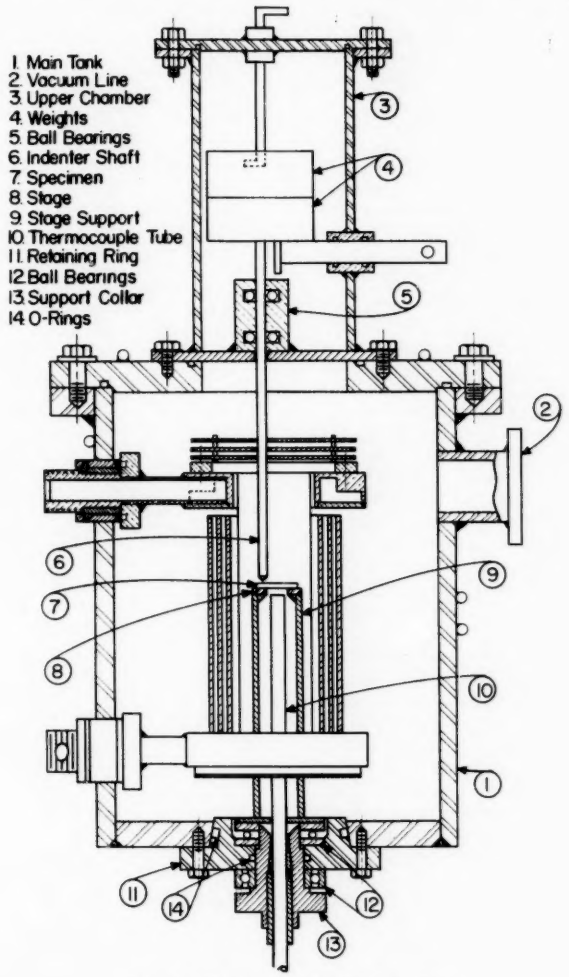

Fig. 1.—Vacuum hot-hardness tester.

The main vacuum tank is 10 in. in diameter and 16 in. high. The top plate is flanged and sealed by an O-ring and bolts. The bottom plate is welded and has a large tapered centered opening into which the stage support assembly is inserted. The 2 in. diameter vacuum line extends from the furnace wall and into an MCF-60 fractionating oil diffusion pump, and thence to a small mechanical vacuum pump. The resistance heating element assembly consists of a cylindrical element of molybdenum sheet supported at the top and bottom by rigid insulated and water-cooled connections. The uniform hot zone is at least 4 in. in length and 2 in. in diameter. Three molybdenum radiation shields of 0.010-in. sheet are arranged in concentric cylinders about the heating element. A top and bottom radiation shield as sembly are also installed to reduce loss of heat from the ends of the heating chamber. The entire furnace tank and important auxiliary parts are externally cooled by water circulating through soldered copper coils. Maximum furnace temperature is 3000 F, limited by the indenter material.

The small upper chamber, also water-cooled, is bolted to the main tank and is sealed by an O-ring. It is evacuated along with the main tank through perforations in the base plate. The chamber centerline is displaced $\frac{1}{2}$ in. from the main tank centerline to

[1] The boldface numbers in parentheses refer to the list of references appended to this paper.

permit off-center loading of the indenter shaft on the specimen. In this manner the specimen may be rotated on the stage and numerous readings taken on a single specimen. The molybdenum indenter shaft ($\frac{1}{2}$-in. rod) is aligned and supported by a frictionless double ball-bearing fitting in the upper chamber. Selected weights are placed on the end of the indenter shaft. The weight may be applied to the specimen or released by means of an eccentric cam arrangement which is manually controlled from outside the chamber. Weights may be changed by removing the top plate of the upper chamber which is bolted and gasketed. The indenter shaft has a sapphire point mechanically bonded to the lower tip. This sapphire is ground to the shape of a 136-deg pyramid which is the standard Vickers configuration. The indenter shaft and sapphire tip are permanently in the hot zone and at the same temperature as the specimen when the hardness impression is made. Sapphire was selected over diamond for work up to 3000 F because of its greater stability. A total vertical shaft movement of about $\frac{1}{2}$ in. is involved in releasing or impressing the weight on the specimen by means of the eccentric cam assembly. Weights may range between 1 and 10 kg, depending on the temperatures to be used and the type of material to be tested. For refractory metals in general, it would appear that 5 kg is adequate above 1800 F and at temperatures above 2500 F a 1 kg weight may be used with success.

The lower furnace assembly, which is completely removable through the welded bottom plate, includes the specimen stage, stage support column, thermocouple, retaining ring, support collar, ball-bearing races, O-ring seals, and holding bolts. A molybdenum stage is made from solid bar stock and pierced with one central hole for the thermocouple extension and two small holes for alignment pins which project from the stage support column. The support column is a hollow molybdenum pipe which rests on the upper ball-bearing assembly. The thermocouple tube passes through the center of the upper ball bearing and then through a support collar and the lower ball bearing to the furnace exterior. The vacuum seal for the thermocouple is furnished by a rubber hose (not shown) fastened to the lower end of the support collar and around the thermocouple tube by means of hose clamps. The support collar and the retaining ring are water-cooled to protect the two O-rings, one of which seals the support collar to the retaining ring and the other seals the retaining ring to the furnace bottom plate. With this arrangement, the entire stage and thermocouple assembly can be rotated through 360 deg, the thermocouple can be removed for replacement or repair, and the entire system can be lowered out of the furnace by removing the retaining ring bolts.

In operation, the specimen in the form of a circular disk is placed on the stage and the stage assembly is inserted through the furnace bottom. This is facilitated by having the furnace mounted on a table with a hole in the center and space underneath in which to maneuver. The mechanical pump is then started and the vacuum pulls the unit into position in the tapered opening. The bolts are inserted and tightened to make a rigid connection. The system is evacuated to the submicron range and the furnace heated to the desired temperature for the first hardness test. After the load is impressed for a period of 30 sec, it is released and the specimen rotated about 10 deg to provide a fresh surface for the next impression. The usual procedure is to obtain hardness impressions every 200 F while heating the specimen to maximum temperature and also to make impressions at the same intervals during cooling to room temperature. After indentations are made, the cool furnace is opened to the atmosphere, the bottom removed, and the specimen extracted. The hardness impressions are measured with a Vickers microscope, and curves may be plotted with temperature *versus* hardness as coordinates. A study of the curves will disclose which materials have potential good strength and rupture resistance at necessary operating temperatures.

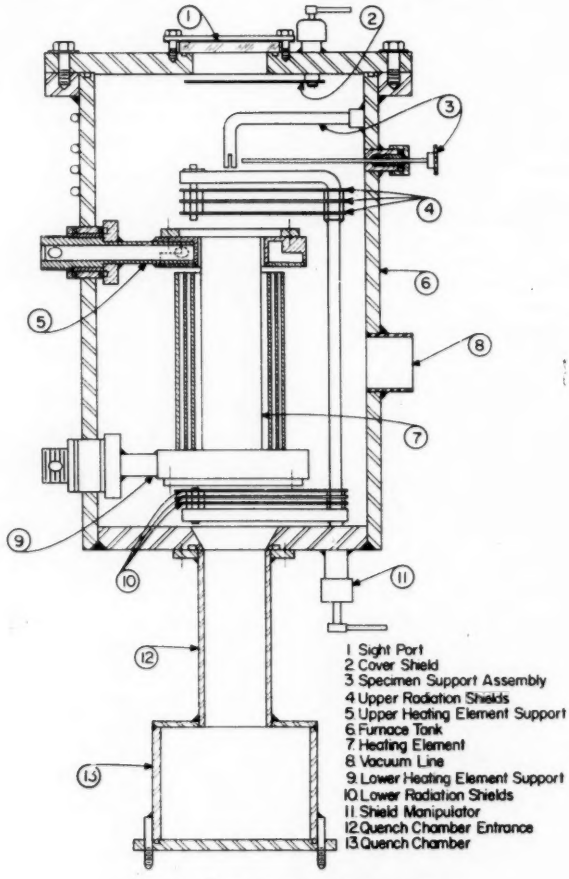

Fig. 2.—Vacuum quenching furnace.

Vacuum Quenching Furnace

This type of equipment is necessary to conduct high-temperature solution treatment or phase diagram studies in a vacuum wherein specimens must be rapidly quenched to retain elevated temperature structures. The basic features of three earlier designs of vacuum quenching furnaces have been described (**3,4,5**). The object of this new design is to incorporate useful features of earlier furnaces and introduce new concepts to improve performance. Temperatures above 4000 F in a vacuum of 0.01 μ can be attained in the apparatus illustrated in Fig. 2.

The heating system is enclosed in a water-cooled stainless steel tank 10-in.

in diameter and 16-in. in height. The ends are flanged to accommodate O-ring-sealed top and bottom plates. The top plate contains a sealed quartz sight window. This window may be used for taking optical pyrometer temperature readings or for aligning and observing specimens in the hot zone. The window is protected from direct radiation by a movable internal molybdenum shield supported by the top plate. The specimen support assembly is designed to permit suspension of specimens in the hot zone on a tungsten wire and permit immediate dropping of the specimens out of the hot zone. The tungsten wire passes through a slotted upper radiation shield assembly which can be swung out of the way simultaneously with the lower radiation shield assembly by means of a connecting pivot rod controlled from the exterior of the furnace. With this system, the hot zone need only be opened during specimen drop and the system components suffer no radiation damage. The heating element supports are of water-cooled copper construction and pass through insulated bushings in the chamber walls to the outside of the tank. Small radiation blocks on the inner walls protect the bushings from direct radiation. A cylindrical tantalum heating element 2 in. in diameter and 8 in. long is supported at the top and bottom by cover plates with enough flexibility for longitudinal expansion of the element under heat. With the ends of the element being water-cooled, the uniform hot zone is approximately 4 in. in length. Surrounding the heating element is an integral unit of three concentric radiation shields. These are suspended from the underside of the upper element support and have a small clearance at the bottom from the lower support. With this arrangement, the shields will not distort or buckle from their own weight and because of the shield clearance no electrical short-circuit will occur in the heater circuit. A thermocouple tube extends from the exterior of the tank wall, through a hole in the radiation shields and terminates at a hole in the heating element. The quench chamber is an appendaged installation, joined to the tank by a bolted O-ring seal. The chamber system is covered with water-cooled copper coils to condense any volatile material arising from the quenching medium. Silicone oil is generally used for quenching because of its low vapor pressure. However, a helium jet impinging on the specimen may be employed or the specimen may be allowed to fall directly on the water-cooled bottom plate.

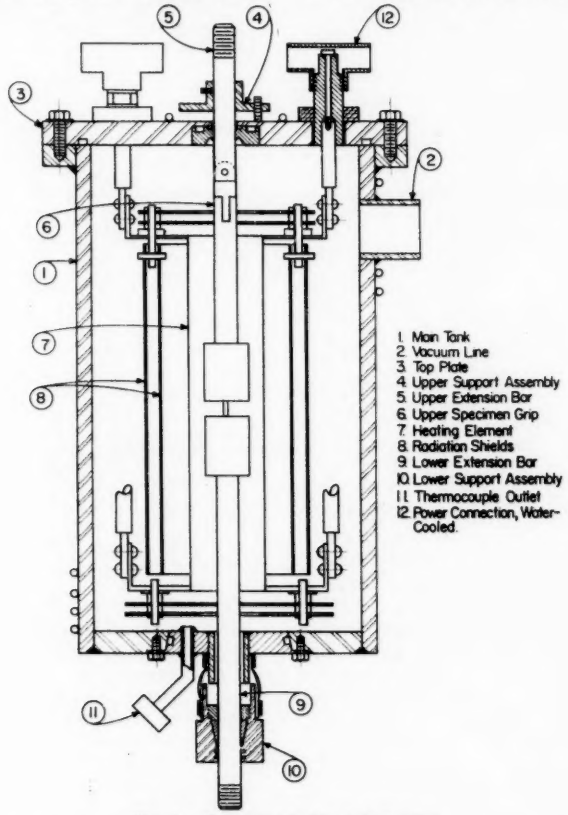

Fig. 3.—Vacuum tension test furnace.

Power supply for this equipment is rated at 25 kva. Control is by means of a saturable reactor fed by the output of a magnetic amplifier working off the thermocouple. The vacuum pumping system consists of an MCF-60 fractionating oil diffusion pump and a Welch mechanical pump together with necessary valves and piping. An economy feature of the power and pumping systems is that they are common to the quenching furnace and to the hot hardness tester which has been previously described. The two units are mounted on a common table, which contains all integral parts for the power, control, water-cooling, and pumping systems.

The substitution of a tungsten heating element in the quenching furnace would permit higher temperatures to be obtained since the 25-power source has adequate capacity for heating the furnace to temperatures above 5000 F.

Vacuum Tension Test Furnace

The purpose of this equipment is to make possible short-time tension testing in vacuum at temperatures to 3000 F. There are no commercial furnaces of this type on the market, although several organizations have offered high-temperature vacuum creep-rupture units that are capable of operation to 3000 F. Missile manufacturers are currently concerned with short-time high-temperature mechanical properties in materials that will go into rockets, so the need for high-temperature tension testing of refractory metals in a protective environment becomes apparent.

Since an existing tension testing machine had to be used, the furnace assembly is designed to be portable, and the dimensions specified will allow working within the existing space limitations. A special table of welded construction houses the tension testing furnace, power transformer, Variac, temperature indicator, and vacuum-pumping apparatus. The legs are fitted with casters. Quick-disconnect water connections and jacks for electrical leads are provided on a central panel board so that the unit can be wheeled into position and hooked up with a minimum of effort. Details of the furnace are shown in Fig. 3.

A vertical steel pivot post supports the furnace tank on bolted extension supports. This allows the furnace to be swung out over the edge of the table when it is placed next to the tension testing machine. The radius of swing is so adjusted that the specimen extension bars protruding from both ends of the furnace can be inserted in the tension testing machine grips while axial alignment of the entire system is maintained. The MCF-60

fractionating oil diffusion pump is connected to the side of the furnace tank by the high-vacuum line elbow. The mechanical pump is mounted on the upper shelf of the table and sufficient length of flexible hose is allowed for free swinging movement of the furnace tank. Large clamps are used for closing or opening various parts of the foreline and roughing line. A 2-in. vacuum valve is inserted between the diffusion pump inlet and the furnace high-vacuum line. The power transformer, Variac, and temperature controller are located on the lower shelf of the table and are placed in such a manner as to counterbalance the weight of the furnace when it is swung out on its support. Power supply is of 15-kva capacity, and furnace input is controlled by means of a hand-operated Variac. The temperature indicator operates from the platinum-platinum rhodium thermocouple in contact with the specimen and is of the direct reading type. Regulation in the system can be maintained within ± 10 F of desired temperature when the specimen is up to temperature, provided careful attention is exercised in manual control.

The furnace tank is constructed of mild steel and is chrome-plated on inner and outer surfaces to reduce corrosion and to facilitate cleaning. Approximate dimensions are 10 in. in diameter and 18 in. in height. External copper cooling coils are employed to prevent overheating of the tank and the O-rings located in the top plate, bottom plate, and lower support assembly. The heating element supports are also internally water-cooled. The top plate is mounted on a flange and is sealed with an O-ring. The lower plate is welded to the bottom of the tank and contains a tapered opening into which the lower support assembly for the specimen extension bar is fitted and sealed with an O-ring. An outlet for the thermocouple tube is also a part of this removable assembly.

The heating chamber consists of a cylindrical molybdenum resistance element surrounded by three 0.010 in. thick molybdenum radiation shields in the form of concentric cylinders. These shields are separated by molybdenum spacers and are suspended from the upper heating element support. Auxiliary sets of triple shields are provided at the top and bottom opening of the heating chamber to prevent excessive loss of heat. Power is supplied through insulated water-cooled copper piping.

The upper support assembly for the grips and extension bars consists of an alignment and locking device. The tension testing machine used provides downward motion of the lower grip, so the upper grip connections are made stationary. Inside the furnace a circular ring-plate containing an O-ring seal fits into a recessed area in the center of the top plate. This ring-plate is welded to the extension bar and provides exact center alignment. To hold the bar in position, a collar on the exterior of the furnace is adjusted by means of a set screw and holddown bolts to provide a positive seat and vacuum seal for the upper extension bar. The whole assembly can be lowered into the furnace by loosening the set screw.

The lower support assembly is removable. The lower extension bar passes through a flexible alignment fitting. This system allows a certain degree of lateral and vertical motion of the grips and pull bars so that uniaxial loading may be applied to the specimen and the specimen may elongate without the presence of deflection stresses. After passing through an internal support bushing, the bar extends to the furnace exterior through a water-cooled double O-ring seal.

The specimen grips and extension bars are made of superalloy or molybdenum alloy bar stock. The external pull rods may be made of ordinary tool steel since they are not in proximity to the heat source. A dial gage may be used for measuring elongation. To load a specimen, the lower support assembly which fits in the tapered bottom plate opening is dropped out of the furnace by removing the holding bolts. The lower specimen grips and extension bar come out with it. The set screw on the upper support assembly is then loosened, a 2-ft long $\frac{3}{8}$-in. diameter steel bar is threaded in the upper extension bar, and the entire unit is pushed through the furnace until the upper grips extend through the lower furnace opening. A specimen is then attached to the upper grips and the unit is retracted into the furnace. At the proper point, the lower grips are attached to the bottom of the specimen and retraction of the unit is continued until the alignment plate on the top extension bar is sealed in the recessed opening in the top plate. Slight tension is applied on the upper bar and the set screw is tightened to make a rigid connection.

Inert Atmosphere Rolling Mill

Figure 4 is a side view of the rolling mill assembly. The mill stand, rolls, and drive assembly are located inside a vacuum-tight L-shaped welded steel plate enclosure. The mill is a constant speed reversing laboratory type mill of 5-hp capacity. The enclosure can be evacuated to 10 μ pressure and all moving parts in the mill are lubricated with vacuum grease. The individual screwdowns extend through vacuum seals to the chamber exterior and are driven up or down simultaneously by a chain drive connecting the two screwdowns to a suitably geared electric motor. Two angled sight tubes give adequate visibility for observing operations inside the chamber. Not shown on the drawing are two 30-in. diameter access ports, one on top of the chamber and one on the side near the mill stand. These ports are used for removal of rolls or other internal furnace components. In addition, the side port is made of transparent plastic which gives an unobstructed large area of observation directly into the side of the mill.

On the left side of the mill are located the combination vacuum line and charging interlock. After the mill chamber is evacuated by a large mechanical pump, the 4-in. vacuum valve is closed, and the material to be processed is placed in the interlock. This section is in turn evacuated,

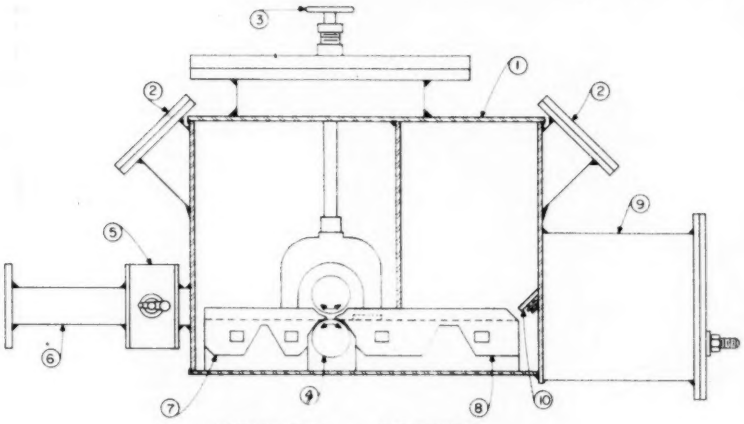

Fig. 4.—Inert atmosphere rolling mill.

after which the entire unit is filled with gettered argon to slightly above atmospheric pressure. The material is pushed by a manipulator onto a vibrating feeder table, through the opened rolls to another vibrator on the entrance side of the mill and into the heating furnace chamber. The furnace is equipped with a molybdenum specimen carrier for sliding material in and out. The furnace entrance is closed by a swinging molybdenum door equipped with radiation shields. It is opened for short periods of time to load or remove specimens. When the furnace is turned on and the specimen has reached temperature, the carrier is pulled out manually through the door. When the carrier is brought up sharply against the vibrator table, the specimen is thrown on the vibrator and moved into the rolls. This entire operation requires no more than 5 sec. An externally operated rod is available which can be used to force the specimen into the rolls if it tends to be deflected. After passing through the rolls, the rolls are opened slightly and the exit side vibrator feeds the specimen back through the rolls to the entrance vibrator. This vibrator is then reversed in direction to move the specimen back to the carrier and from there it is reloaded in the furnace.

In practice, it has been possible to pump the chamber down to 10 μ with a leak rate of 0.1 μ per min. The induction type molybdenum furnace has reached temperatures of 3500 F in an argon atmosphere with a power input of 22 kw at 3000 cycles. No coil arcing has been observed at these loads, and higher temperatures can probably be reached. There is no outgassing in the mill system because a minimum of refractory ceramic materials are used for insulation purposes. The furnace has been operated in a 25 μ vacuum at temperatures above 3000 F.

The design of the heating furnace illustrated in Fig. 5 is unique and merits some detailed discussion. Most induction furnaces with integral susceptors are built with a vertical coil arrangement since this simplifies the supporting structure for coil, susceptor, and radiation shields. However, a horizontal assembly was necessary in this case because the design of the mill chamber required a molybdenum specimen carrier to slide out of the furnace and directly into the vibrator feeding device. The three main problems in design were to suspend the coil, the radiation shields, and the susceptor in such a manner that sagging and distortion did not occur at temperatures up to 3500 F. The susceptor was made from 0.062-in. thick molybdenum sheet welded into a 3-in. cylinder about 13 in. long. A water-cooled copper plate with a 3-in. diameter hole in the center supports the front of the susceptor. The susceptor lies loosely in this hole and may slide in it during thermal expansion. The back of the susceptor is held rigidly by extending the molybdenum tray guide racks outside the heating zone. The 6-in. diameter 21-turn coil had to be mounted rigidly to eliminate weight and vibration difficulties, and the individual coil turns had to be insulated in a suitable manner. Fused silica thermocouple protection tubes were selected for this application. Since the tubes are behind the radiation shields and the water-cooled coil, they do not become heated enough to present outgassing problems. A brass bolt was soldered at a horizontal point on each coil turn, and an insulating tube was slipped over the bolt. Two stainless steel plates, one on each side of the coil, acted as basic supports. Holes were drilled at one coil-turn intervals in the plates to receive the insulating tubes. The final assembly on each side of the coil consisted of a stainless steel plate with a row of holes, an insulating tube in each hole, and a brass bolt in each tube. These two stainless steel plates were combined with two additional plates to connect the front copper plate to the furnace back plate rigidly. Two concentric 0.015-in. thick molybdenum cylinders were formed from sheet and are used for longitudinal radiation shields while three end radiation shields protect the water-cooled backing plate from the heated susceptor. An additional stainless steel sheet is inserted between these shields and the water-cooled plate to further reduce the temperature gradient. The two water-cooling circuits operate at 50-lb pressure. The heat protection tubing is $\frac{1}{4}$ in. in outside diameter, and the induction coil tubing $\frac{3}{8}$ in. in outside diameter. The water temperature is 130 F at 3500 F furnace temperature on both lines.

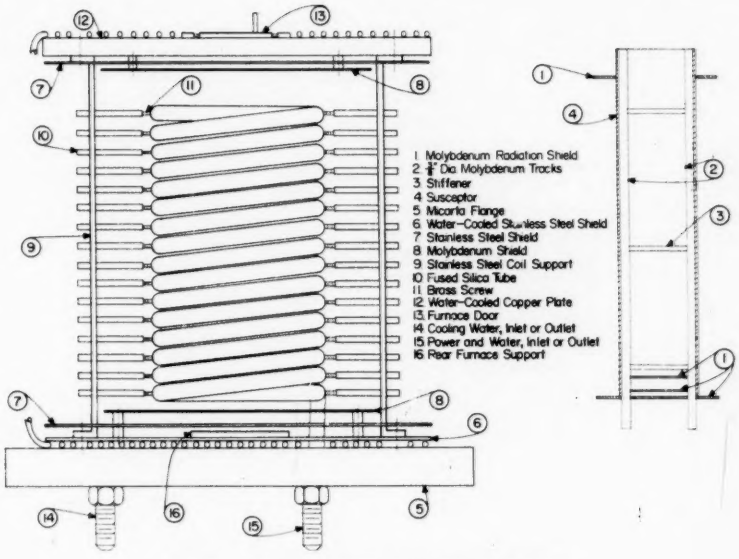
1 Molybdenum Radiation Shield
2 ¼" Dia Molybdenum Tracks
3 Stiffener
4 Susceptor
5 Micarta Flange
6 Water-Cooled Stainless Steel Shield
7 Stainless Steel Shield
8 Molybdenum Shield
9 Stainless Steel Coil Support
10 Fused Silica Tube
11 Brass Screw
12 Water-Cooled Copper Plate
13 Furnace Door
14 Cooling Water, Inlet or Outlet
15 Power and Water, Inlet or Outlet
16 Rear Furnace Support

Fig. 5.—Inert atmosphere mill-heating furnace.

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A Reliable Technique for Measuring Brush Wear in an Atmosphere Containing Silicone Vapor

By J. S. AXELSON and F. M. PRECOPIO

The accelerated wear of carbon brushes in machines insulated with silicone materials is well known. The test methods employed by investigators studying this problem, however, have cast some doubt on the validity of the results. Because of many conflicting brush vendor claims and contradictions in the literature, a critical examination of the test methods employed was made so that these differences might be understood and perhaps resolved.

The technique described here uses a large number of brushes (for better statistical interpretation) running on slip rings in an enclosed chamber where the silicone atmosphere is accurately controlled by using a reservoir of silicone fluid of appropriate vapor pressure. Using this method, very reproducible wear data have been obtained on a given grade of brush many months after the original tests were run.

Brushes, supposedly designed for high performance in the presence of silicones, were obtained from five vendors. According to our tests, three of these show no improvement over the standard control brush and the best performer in a silicone atmosphere failed to show the low wear rate of the control brush in a normal atmosphere

THE accelerated wear of carbon brushes in machines insulated with silicone materials is well known. Marsden and Savage investigated the problem in some detail using refined laboratory techniques and proposed a mechanism to explain this unusual effect (1).[1] In 1956, a patent was granted to Moberly which disclosed the neutralization of the silicone effect by the use of partially polymerized diallyl phthalate either in the brush or in the machine (2). No data were presented, but it was implied that tests were conducted in actual machines. Another patent issued to Ramadanoff disclosed a treatment for improving life of carbon brushes in the presence of silicones, and although wear data are given, the method of taking the data is not described (3). Recently, further work has been reported on this problem in which the testing was carried out in an enclosed chamber where the silicone vapor was generated by passing current through coils which had been coated with silicone resin or by immersion heaters wrapped with tape and then treated with silicone varnish (4).

Because of many conflicting vendor claims and contradictions in the literature, a critical examination of the test methods employed was made so that these differences might be understood and perhaps resolved (2, 4).

Brush wear is a complex function of many variables (5, 6). Thus, although accelerated brush wear is generally observed in silicone-insulated machines, it is unlikely that differences among various brushes can be accurately established in actual motor tests whether the machine is operating in the field or under controlled duty cycles. The results of tests run on silicone insulated d-c machines under controlled loading have been difficult to interpret.

The use of slip-ring tests conducted in an enclosure with controlled atmosphere provides a definite improvement over actual motor tests, but if the atmosphere is not properly controlled, the results may be open to considerable question. The use of "fumer coils" copper coils coated with silicone resins or immersion heaters which have been taped and then coated with silicone resins—as a source of silicone atmosphere is not reliable for a number of reasons. It is difficult to control the temperature of the source, the amount of resin in the source, and, hence, the amount of volatiles evolved. Different resins and even different batches of the same resin evolve different amounts of volatiles at any given temperature. As the coil is heated, the resin cures, and the rate of evolution of volatiles changes. Since the extremely important role of silicone concentration has been well established, the use of this technique cannot lead to reliable and reproducible results (1). Reproducible data were obtained by Marsden and Savage who studied brush wear on a slip ring in a bell jar where the concentration of silicone was accurately maintained by the use of pure silicone fluids of known vapor pressure (1). The technique described in this paper uses this same principle, but the apparatus has been designed for the simultaneous running of 20 brushes, a large enough number for proper statistical interpretation of the results. The equipment also uses commercial-size brushes fitted into standard brush holders used in the General Electric Kinamatic line of d-c machines. The design will be discussed

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[1] The boldface numbers in parentheses refer to the list of references appended to this paper.

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in detail below. The data were fitted to a least squares line showing limits of error. By this method, the data enable a differentiation of the wear behavior of different grades and makes of brushes quite well.

The slip-ring test is weak because it ignores the effects of current switching or commutation. A partial answer to this difficulty will be provided by running commutation tests under carefully controlled conditions. This phase will be the subject of another paper in the future.

Description of the Apparatus

The apparatus used in this work consisted of a chamber 8 in. wide, 16 in. high, and 21 in. long, fitted with glass panels to allow good visibility into the chamber from two sides (Fig. 1). The shaft supporting the copper slip ring was fitted lengthwise in the chamber passing through an airtight carbon seal in each end and mounted on external pillow block bearings. The external bearings were necessary to avoid contamination of the atmosphere in the chamber from bearing grease. Ten commutator copper rings, $4\frac{3}{4}$ in. in diameter and 1 in. wide, were assembled on the shaft. The rings were insulated from the shaft and from each other by thermally stable insulating materials containing no silicone. The rings were slotted to simulate mechanical action of a commutator. The shaft was driven at 3200 rpm by an externally mounted d-c motor for accurate speed control. The chamber and shaft were cadmium plated to prevent corrosion and facilitate cleaning. All mating parts of the chamber were machined to minimize leakage. The chamber was designed so that it could be disassembled easily. The parts were cleaned thoroughly in toluene and baked dry before reassembly.

Twenty brush holders were mounted on frames running the length of the chamber. Ten holders were mounted at the top of the chamber and ten at the bottom in such a fashion that two tracking brushes, one positive and one negative, would run 180 deg apart on each ring. General Electric constant-pressure brush holders were used exerting a pressure of 4 psi on $\frac{3}{4}$ by $\frac{3}{8}$-in. brushes. For these tests, a current density of 60 amp per sq in. was maintained on the brushes which were series-connected and the current was supplied by a 6.5 kw motor-generator set. For measurement of brush temperatures, thermocouple wells were drilled in the tops of certain brushes down to $\frac{3}{8}$ in. from the face. Thermocouples were inserted and connected to a multiswitch which was connected to a millivoltmeter. To give a measure of the work performed by the d-c drive motor, an ammeter was connected in series with the armature circuit. This measurement was related to the total friction developed in the test chamber.

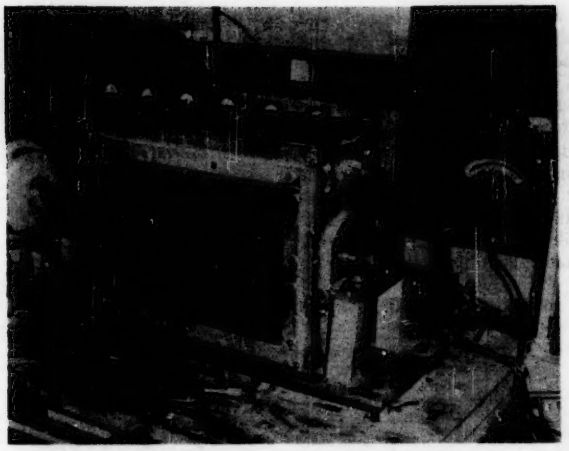

Fig. 1.—Controlled atmosphere brush testing equipment.

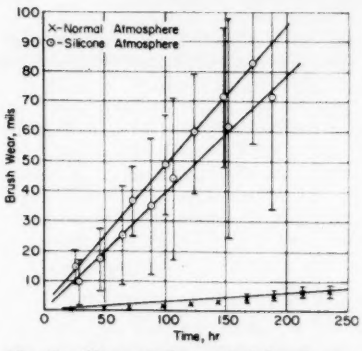

Fig. 2.—Wear of the control brush as a function of time in normal and silicone atmospheres.

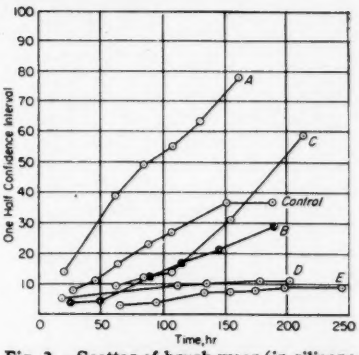

Fig. 3.—Scatter of brush wear (in silicone atmosphere) data for groups of 14 as a function of time.

An attempt was made to record wear rate continuously by means of a strain gage mounted on a flexible beam which in turn rested on a pin mounted in the top of the brush. This technique was abandoned because of the extreme sensitivity of the recorder to humidity and temperature changes and the length of time necessary to zero the brushes in after each measurement. We plan to use a small linear variable differential transformer (electromechanical transducer) to perform this function in the future. With this device, voltage drop can also be measured when a reading on brush wear is taken. No voltage drop data were recorded in the program reported here. For these tests, the brushes were removed periodically and measured with a micrometer to determine wear.

The space between the bottom brush holder rigging and the floor of the chamber housed a shallow removable stainless steel tray. When a silicone atmosphere was desired, this tray was filled with a silicone fluid. After some exploratory experiments, General Electric silicone fluid SF96-500 was chosen for this investigation since the wear rates produced were not too excessive and yet were sufficiently large to give measurable results in a short time.

Test Results and Discussion

The object of this investigation was to develop a reliable method for studying brush wear in the presence of a silicone atmosphere and to apply this method in evaluating brushes presently available to the electrical industry. The major brush manufacturers were asked to submit the best grade of brush available for use in the presence of silicones. These brushes were compared with a standard commercial grade brush as a control which was chosen because it is used extensively in d-c general-purpose machines and for which no claims are made as far as resistance to wear in this type of atmosphere is concerned. Only 7 of the 10 rings available were used in these tests, so a total of 14 brushes (7 negative and 7 positive) were tested during each run. The slip rings were cleaned, using a medium seater stone before each run. The

chamber was thoroughly cleaned and the brushes were allowed to run until a good seat had been established. The zero wear measurement was then made and subsequent measurements were made every day, until a 200-hr test period had elapsed. All the brushes were run in the total absence of silicones first and then the procedure was repeated in a silicone atmosphere.

Wear measurements were taken using a micrometer held in a jig which allowed exact positioning of the brush. Measurements were taken at three positions across the face of the brush and the average reading was recorded. Fourteen readings were recorded for each wear period. A least-squares plot of the average of 14 readings as a function of time was then made to determine the wear rate. The difference in wear rate between the positive and negative brushes was generally so small that it was considered appropriate to combine these results and average 14 readings.

TABLE I.—SLOPES OF WEAR VERSUS TIME CURVES.

	Normal Atmosphere	Silicone Atmosphere
Control (A)	0.06	0.94
Control (B)	...	0.78
Brush A	0.06	1.08
Brush B	0.11	0.86
Brush C	0.09	0.75
Brush D	0.08	0.32
Brush E	0.13	0.23

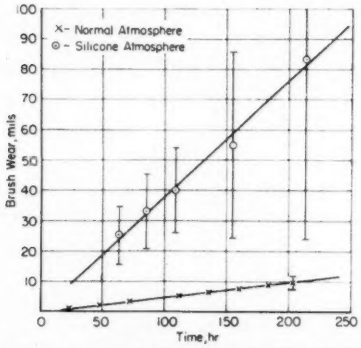

Fig. 6.—Wear of brush C as a function of time in normal and silicone atmospheres.

Figure 2 shows the wear rate of the control brush in normal and silicone atmosphere. Its wear rate is high in the presence of silicone. Figure 2 shows the wear rate of the control brush 9 months after the original data were taken using a new set of brushes and a new batch of SF96-500 silicone oil. The comparatively good agreement with the earlier data supports the hypothesis that this technique can lead to better reproducibility of results than heretofore available. The difference between the two runs can be ascribed to a number of variables which we cannot control perfectly but which, no doubt, contribute to error; variation in brush quality, variations in composition of the silicone oil, in ambient temperature and humidity, and in brush temperature, are a few. Figure 2 and subsequent graphs indicate the 95 per cent confidence limits about the average of the experimental points. It is interesting to note that the spread in the data was very high for brushes showing high wear rates in silicone but was quite small for brushes showing good wear characteristics. This is clearly shown in Fig. 3 which plots one half the confidence limit as a function of time for the brushes tested.

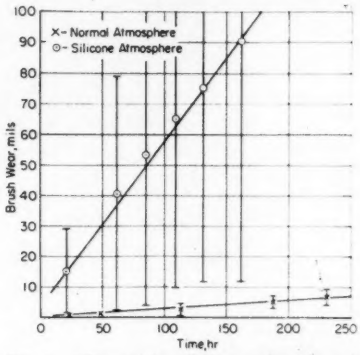

Fig. 4.—Wear of brush A as a function of time in normal and silicone atmospheres.

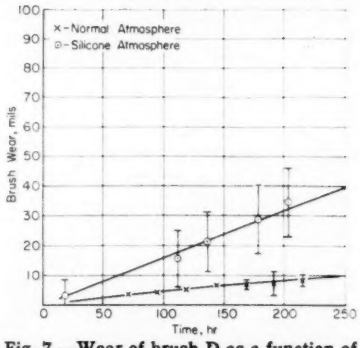

Fig. 7.—Wear of brush D as a function of time in normal and silicone atmospheres.

Figures 4 to 8 show the results obtained with the other brushes tested. In all cases, the wear rate in silicone was substantially higher than in the absence of silicone, but there were distinct differences among brushes. Three of the brushes, A, B, and C, were very poor, while D and E, were decidedly superior. Brush E showed the lowest wear rate in silicone. However, D should also be considered acceptable since its wear rate in silicone did not differ greatly from that of E. Table I summarizes the data presented in the graphs.

Acknowledgment:

The authors acknowledge helpful discussions with D. G. Flom of the General Electric Research Laboratory and L. S. Nelson of the General Electric Lamp Development Dept. The design of the test equipment was primarily the contribution of the Electromechanical Unit of the General Electric Direct Current Motor and Generator Dept.

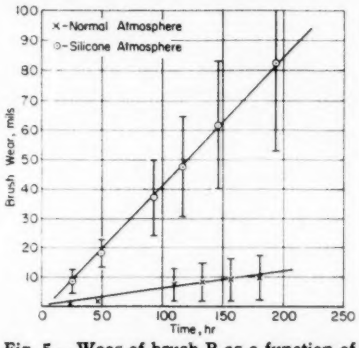

Fig. 5.—Wear of brush B as a function of time in normal and silicone atmospheres.

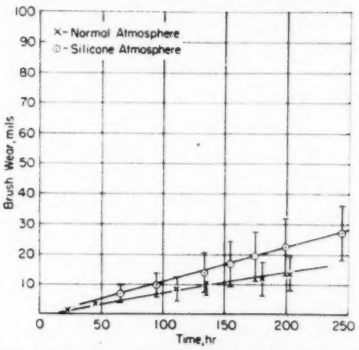

Fig. 8.—Wear of brush E as a function of time in normal and silicone atmospheres.

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Hardness, Abrasion, and Wear Resistance Testing of Plastics*

BY LADISLAV BOOR

A great variety of tests for these three properties of plastics and related materials may be found in the ASTM Book of Standards. Such profusion of methods can confuse the uninitiated and even, at times, the expert. In this paper, the author reviews the methods available and discusses the interpretation and applicability of the results.

HARDNESS as an index of the resistance of a plastics substance to temporary or permanent deformation has been a useful measure of technological sufficiency in service and chemical and physical changes in processing, such as cure, state of polymerization, and reversible and irreversible degrading effects caused by temperature, light, moisture, and oxygen absorption. Wear and scratch resistance have had many interpretations each associated with a particular class of application, and with the response of the material to the specific deforming forces.

Since plastics cover an enormous range of resistance to indentation—from the consistency of freshly baked bread to that of the softer metals—a variety of instruments has been developed to measure significant differences in the respective classes of plastics.

Hardness Testing

The general term "hardness" has been defined by L. B. Tuckerman (1)[1] one of the oldest living veterans of the hardness testing field, as "a hazily conceived-conglomeration or aggregate of properties, more or less related to one another." One of the earliest systematic concepts of hardness was developed by Reamur in 1722. A steel bar, heat treated to produce a hardness gradient from dead soft at one end to glass hard at the other, was scratched with an unknown; the point on the bar at which the unknown would scratch was an index of its hardness (2). A century later, the Mohs scale of minerals was introduced—talc equal to one and diamond ten. Other forms of quantitative measures of scratching and indentation were devised in particular industries, all providing a quantitative index for some specific purpose. In 1900, J. A. Brinell developed his ball indentation test and put it on a quantitative basis—specifically for ferrous metals and alloys. It measures residual indentation made by a 10-mm ball with either of two fixed loads, and the method has since been elaborated by Meyer and others. In 1906, the scleroscope was invented and is still widely used in metals industries. Hardness of metals is measured by the height of rebound of a diamond-pointed tup falling from a fixed height.

Stanley Rockwell introduced the first models of the Rockwell tester in 1919, and in the intervening years this instrument has been refined and a "superficial" model added. It has largely replaced the other hardness testers used in the metals industry. In Europe, the Vickers diamond pyramid instrument, introduced about 1925, is widely used. In the U. S. the Knoop microhardness tester, developed at the National Bureau of Standards in 1939, is used primarily for research in microhardness of metals and alloys; the commercial version of this instrument is known as the "Tukon" (3).

Let us consider what these systems are measuring. Characteristic of all is the use of a spherical, pyramidal, or conical indenting shape made of a substance (hardened steel, carbide, sapphire, or diamond) relatively unaffected by the test material to displace or indent the test material under controlled force. The effect is measured by the dimension of the resulting displacement (diameter or depth). Hence, we can say these systems measure the resistance of a material to being pushed around.

From a physical point of view, this index of resistance is related to the modulus—the specific stress-strain relation defined in tension as Young's modulus. It has been demonstrated that, within limits, this relation holds equally well for compression; hence, the indentation of a very small portion of the material is a good index of projected behavior in tension, compression, shear, and torsion. In the case of metals subject to different heat treatments, cold work or of dissimilar metals or substances, for example steel *versus* copper, the indentation hardness would be influenced not only by modulus difference, but also by the area inclosed in the graph of unit stress plotted against deformation beyond the yield point. For example, the modulus of high-carbon steel from the annealed to the hardened condition does not change significantly from 30 million; however, the area under a curve, plotting stress against strain to the point where the total stress is exactly counterbalanced by the resistance of the progressively increasing area supporting the load, will be enormously different. Annealed high-carbon steel will test Rockwell hardness C 20; in the hardened condition it will test Rockwell hardness C 65 to 70.

In metals the resistance to indentation has been developed as a valuable index of composition, heat treatment, work-hardening properties, degree of spring, and elastic properties. Because of its simple form, rapid measurement, and the fact that the specimen is not destroyed in testing, it has a firm place in today's technology.

It was natural that when plastics began to take their place as engineering

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* Presented at the Fifteenth Annual Technical Conference of the Society of Plastics Engineers, New York, N. Y., Jan. 1959.

[1] The boldface numbers in parentheses refer to the list of references appended to this paper.

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materials, the same approach was developed to use resistance to indentation not only for its own sake but to infer other engineering properties. Let us re-examine the purpose of a hardness test and what it should tell us. There are many situations in which hardness index is sought for its own sake: for instance, to measure the indentation of a furniture caster into a slab of floor tile when loaded by a 250-lb subject, or the tooth marks of a one-year-old on a plastic teething ring, or the impression of a sharply pointed rock on a shoe sole. Such inferences from indentation hardness are straightforward.

There is also the category of tests in which identation hardness helps infer other properties such as tensile or compressive strength, or modulus. In this area great care must be taken to establish such a correlation by rigorous comparisons. Although there is a fairly useful correlation between indentation hardness of steels and nonferrous metals and their respective tensile strengths, such relations cannot be uncritically carried over to plastics without a systematic study of the correlations. It is highly probable that such inferences will apply only in a limited way to a given class of plastics.

Caution should be exercised in inferring other properties such as wear, abrasion, and mar resistance from indentation hardness tests; for example, a mar resistance test of soft plastic using falling abrasive may show it to be much better than glass by the same test (4).

Indentation Hardness Methods

The Brinell method using loads of 3000 and 500 kg on a 1-cm ball and measuring residual indentation by means of a magnifier was never adopted for plastics, not only because the elastic recovery, both immediate and delayed, produced no sharply defined edge of the indentation but also because the lowest load was too high for most plastics.

Although the Tukon indenter (3) has been used for research and exploration in anistropy, it has not received wide acceptance for general control work, principally because it measures residual identation with a microscope, which in most plastics is very time-dependent.

The Rockwell index of hardness is based on a depth of residual indentation measured directly. It was adopted sometime in the 1930's by ASTM Committee D-9 on Electrical Insulating Materials, and later was taken over by Committee D-20 on Plastics. It is currently designated as ASTM Method of Test for Rockwell Hardness of Plastics and Electrical Insulating Materials (D 785).[2] The standard long-stroke Rockwell instrument operates on the following principle: the indenters used in testing plastics are hardened steel spheres with diameters of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in. A minor load of 10 kg is imposed on the specimen and the dial is set at zero. A major load is then applied for a fixed time. The major load is then removed, the minor load remaining. After a fixed time, a reading is taken that is the increment of indentation remaining after removal of the major load on reversed scale, that is, the large numbers representing small indentations (greater hardness).

[2] ASTM Method of Test for Rockwell Hardness of Plastics and Electrical Insulating Materials (D 785), 1958 Book of ASTM Standards, Part 9, p. 273.

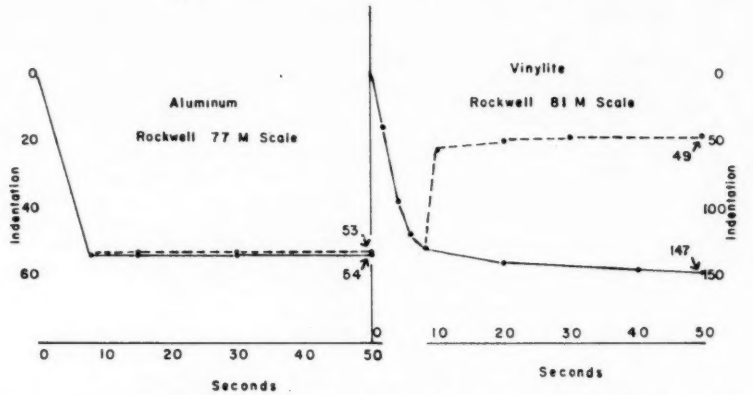


Fig. 1.—Time-indentation relationships. Rockwell $\frac{1}{4}$-in. ball, 100-kg load (M scale).

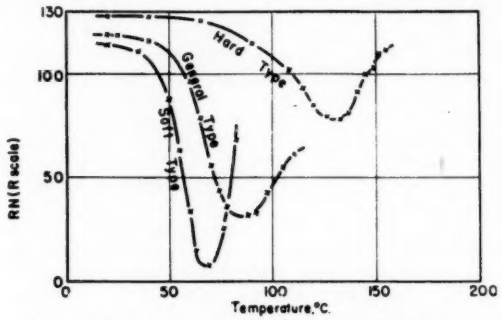


Fig. 2.—Typical curves for rigid polyester cast resins.

To cover the wide range of hardness in plastics, a variety of loads and indenters is used:

	Scale	Major Load	Penetrator
Low hardness...	R	60	$\frac{1}{2}$-in. ball
	L	60	$\frac{1}{4}$-in. ball
	M	100	$\frac{1}{4}$-in. ball
High hardness..	E	100	$\frac{1}{8}$-in. ball

These load-penetrator combinations will cover the range from the softer rigid materials such as plasticized vinyl plastics, to the hardest phenolic and melamine asbestos and glass-filled compounds. It should be noted that the Rockwell methods described are based on the behavior of metals in which negligible recovery occurs after indentation by the major load. This however, does not hold for many of the plastics. These relationships were studied in a variety of plastics (5) and it was found that many plastics recovered from the major load indentation with time. Time-indentation relationships are shown in Fig. 1. As a result of this work, method B of ASTM Method D 785 was developed for measuring Rockwell indentations *under major load*, which is called the Rockwell alpha scale. The Rockwell hardness R scale ($\frac{1}{2}$-in. ball, 60-kg major load) has been used to study mechanical properties and their dependence on temperature of polyester and vinyl plastics (6). Typical curves obtained by this procedure are shown in Fig. 2. The lower inflection point in these curves does not signify a sudden increase in indentation hardness but the transition to a rubbery elastic behavior evidenced by elastic recovery when the major load is removed. On the alpha scale, the readings at this point would take a sudden drop to values beyond the lower limit of the instrument.

The Barcol indenter, widely used in plastics field, is now being considered as the basis for an ASTM method. This portable spring-loaded instrument was originally designed to distinguish various alloys of aluminum. The indenter is a truncated cone with a 26-deg angle and a flat tip 0.0062 in. in diameter.

The scale reads 0 to 100 direct hardness. (See Fig. 3.)

Scratch Hardness Methods

The Bierbaum hardness tester shown schematically in Fig. 4 has also been widely used in the plastics industry (7,8). It does not measure indentation hardness directly but determines the width of a scratch made by a precisely ground point exactly loaded and drawn over the surface of a plastic. In this case, residual width is measured; a deep furrow that recovered after the scratching point had passed would be rated high on the scale. Typical Bierbaum scratch values are as follows:

Vinylidene chloride	5 to 9
Ethyl cellulose	5 to 8
Cellulose acetate-butyrate	4 to 19
Cellulose nitrate	8 to 16
Polystyrene	9 to 15
Cellulose acetate	10 to 20
Polyester, unfilled	10 to 15
Methyl methacrylate	15 to 19
Phenolic, molded	17 to 22
Melamine laminate	28 to 32
Plate glass	700 to 800

An excellent review of the history of scratch hardness measurements was made by Bernhardt (9) who also made an analysis (10) of the four variables involved in making a scratch:

1. load on indenter,
2. velocity of deformation,
3. tangential force to propagate the scratch, and
4. dimensions of displacement.

Bernhardt used a conical rounded sapphire point with a radius of approximately 100 μ. His conclusions indicate that in addition to the indenting force and the force at right angles which propagates the indentation into a groove, the coefficient of sliding friction between the specimen and the indenter is an important factor in scratch resistance.

ASTM Method of Test for Deformation of Plastics Under Load (D 621),[3] an indirect method of test, has had a long history of use in electrical insulating materials. Instead of the penetrator being smaller than the specimen, as is the case with indentation tests, the surface applying the load is larger than the specimen and the result is a compression test where the entire specimen carries the compressive load.

Two variations of Method D 621 for rigid and nonrigid plastics are in use. Method A gives the index of rigidity of plastics at service temperatures and also evaluates their ability to withstand compression in assemblies of conductors and insulators held together by bolts, rivets, and other fastening devices. Method B determines the extent to which a plastic will return to its original dimensions after being compressed.

In the very soft range comparable to the consistency of pure gum rubber in its filled and vulcanized forms, durometer A used in ASTM Method D676[4] covers the softness range from pure gum to tire-tread types of vulcanizates; model D used in Method D 1484[5] overlaps the high range of model A and includes harder compounds such as hard rubber and rigid plastics. The portable, spring-loaded instruments were developed for elastomeric and rubber-like materials, and the two methods cited above are limited to this use. Revised versions of these methods have been written making them applicable to plastics as well as rubber; the designation of the method for plastics is D 1706.[6]

The indenting points, although the same in diameter, differ in angle and sharpness, model A having a 35-deg truncated cone, a point 0.031 in. in diameter, and a maximum load of 822 g; model D has a 30-deg cone point with a 0.004-in. radius sphere on the end and maximum load of 10 lb. The Rex gage uses the same principle. All are calibrated to a direct hardness reading of zero to 100.

A dead-weight-load instrument using a 3-lb load on a spherical indenting point 0.0938 in. in diameter surrounded by a presser foot 0.625 in. in diameter with a 5-lb load used for measuring hardness in the soft range of elastomers is described in ASTM Method D 314.[7] Readings are made in direct indentation in thousandths of an inch (inverse hardness).

Fig. 3.—Barcol impressor.

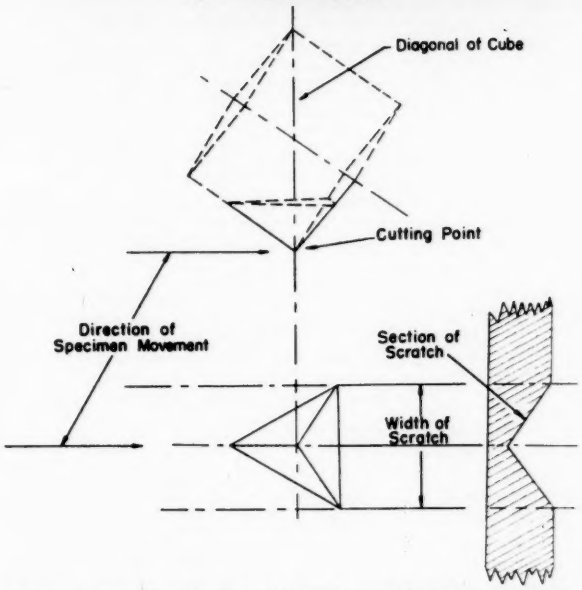


Fig. 4.—Schematic drawing of the Bierbaum Microcharacter tester.

[3] ASTM Methods of Test for Deformation of Plastics Under Load (D 621), *Ibid.*, p. 369.

[4] ASTM Method of Test for Indentation of Rubber by Means of a Durometer (Tentative) (D 676), *Ibid.*, p. 1303.

[5] ASTM Method of Test for Penetration of Hard Rubber by Type D Durometer (Tentative) (D 1484), *Ibid.*, p. 1698.

[6] ASTM Method of Test for Indentation Hardness of Plastics by Means of a Durometer," (D 1706) 1959 Supplement to 1958 Book of ASTM Standards, Part 9, p. 37.

[7] ASTM Method of Test for Hardness of Rubber (D 314), *Ibid.*, p. 1297.

Other methods with some variations in indenter load and method of mounting are also used. The instrument used in ASTM Standard Method of test for Indentation of Rubber by Means of the Pusey & Jones Plastometer (D 531)[8] has been modified by many workers, two of the best known versions being the Admiralty and Brooklyn Naval Materials Laboratory Indenter (MLI). Another similar instrument is used in ASTM Method of Test for International Hardness of Vulcanized Natural and Synthetic Rubbers (D 1415).[9] A spherical indenting penetrator 2.5 mm (0.1 in.) in diameter is used with a minor load of 30 g and a major load of 580 g. A presser foot 20 mm (0.8 in.) in diameter with a 600 to 900-g load surrounds the indenter. An electrical vibrator is used to overcome friction. This instrument has been found suitable for investigating indentation hardness in the temperature range from 200 to −80 F where other instruments were deficient at either the high or low portion of the temperature range.

Recently Carlson (11) developed a conversion formula relating the Shore and other spring-loaded instrument scales to the readings on dead-weight instruments calibrated in depth of indentation. These relationships hold only in the temperature range in which the response of the materials is instantaneous. At temperatures where the materials exhibit delayed elasticity and creep, the conversions must be corrected for specific materials.

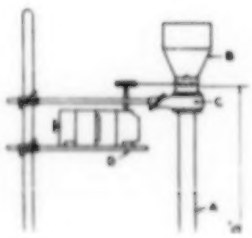
The lowest of the hardness ranges—foams, sponges, expanded and cellular plastics and elastomers—is so low that it is not usually associated with hardness at all. In ASTM Specification and Method of Test for Latex Foam Rubbers[10] a flat circular foot 8 in. in diameter (50 sq in. in area) is used to indent a specimen at least 12 in. square. A minor load of 1 lb is used to obtain a

Another valuable tool for measuring effect of compressive forces in soft materials like sponges and foams is the Schiefer compressometer (12) in which load may be varied and resulting indentation measured.

To summarize, hardness testing is a valuable, nondestructive method for classifying compounds and their relative resistance to transient and permanent deformation. It is a quick method of following changes in physical properties due to polymerization, solvent removal, phase changes and aging effects. The heart of any successful use of an indentation test is the selection of a specific procedure suited for the application, and a continual confirmation of the correctness of the indications on samples of known behavior history.

Abrasion and Wear

It should be pointed out that although the general concepts of hardness, abrasion, and wear are commonly associated, there is no consistent relationship between any of the indentation hardness indices and any of the aspects relating to abrasion and wear. This is inherent, first, in the various approaches to indentation hardness, such as temporary and permanent indentation and, second, in the various concepts of what constitutes abrasion and wear, how it is caused, and quantitative measures of its effects.

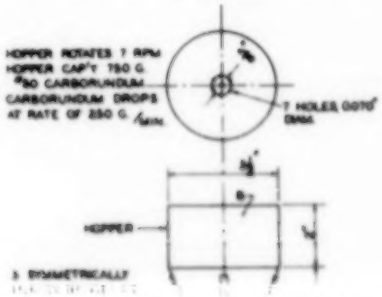


tableware. Methods for measuring these effects are described in the following:

In the ASTM Method of Test for Mar Resistance of Plastics (D 673),[11] a controlled stream of abrasive particles is allowed to drop onto the surface of a plastic held at a 45-deg angle to the axis of fall (13). Effects of progressively greater amounts of abrasive are measured by means of optical properties, gloss, or transmission. (See Fig. 5.)

Closely related is the ASTM Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products by the Falling Sand Method (D 968)[12] in which a standard sand falling against a test surface is used. Its most important use has been for evaluation of protective films. In both these methods, the amount of surface material removed cannot be weighed and the quantitative effects must be judged visually, optically, or by relating the weight of abrading material to the thickness of film worn through.

In order of severity the next method is the ASTM Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products with the Air-Blast Abrasion Tester (D 658).[13] The instrument used was developed at Bell Telephone Laboratories and has an important place in the protective coatings industry and can be used for the evaluation of many plastics surfaces.



THE accelerated wear of carbon brushes in machines insulated with silicone materials is well known. Marsden and Savage investigated the problem in some detail using refined laboratory techniques and proposed a mechanism to explain this unusual effect (1).[1] In 1956, a patent was granted to Moberly which disclosed the neutralization of the silicone effect by the use of partially polymerized diallyl phthalate either in the brush or in the machine (2). No data were presented, but it was implied that tests were conducted in actual machines. Another patent issued to Ramadanoff disclosed a treatment for improving life of carbon brushes in the presence of silicones, and although wear data are given, the method of taking the data is not described (3). Recently, further work has been reported on this problem in which the testing was carried out in an enclosed chamber where the silicone vapor was generated by passing current through coils which had been coated with silicone resin or by immersion heaters wrapped with tape and then treated with silicone varnish (4).

Because of many conflicting vendor claims and contradictions in the literature, a critical examination of the test methods employed was made so that these differences might be understood and perhaps resolved (2, 4).

Brush wear is a complex function of many variables (5, 6). Thus, although accelerated brush wear is generally observed in silicone-insulated machines, it is unlikely that differences among various brushes can be accurately established in actual motor tests whether the machine is operating in the field or under controlled duty cycles. The results of tests run on silicone insulated d-c machines under controlled loading have been difficult to interpret.

The use of slip-ring tests conducted in an enclosure with controlled atmosphere provides a definite improvement over actual motor tests, but if the been well established, the use of this technique cannot lead to reliable and reproducible results (1). Reproducible data were obtained by Marsden and Savage who studied brush wear on a slip ring in a bell jar where the concentration of silicone was accurately maintained by the use of pure silicone fluids of known vapor pressure (1). The technique described in this paper uses this same principle, but the apparatus has been designed for the simultaneous running of 20 brushes, a large enough number for proper statistical interpretation of the results. The equipment also uses commercial-size brushes fitted into standard brush holders used in the General Electric Kinamatic line of d-c machines. The design will be discussed

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[1] The boldface numbers in parentheses refer to the list of references appended to this paper.

ASTM Method of Test for Resistance of Transparent Plastics to Surface Abrasion (D 1044)[14] tests a specimen 4 in. in diameter mounted by a center hole on a turntable which is rotated against weighted abrasive wheels. The effect is measured opticaily or by weight loss. A modification of the Taber abrader is used by the NEMA[15] for testing laminates in which the abrasive wheels support abrasive cloth which is renewed for each test.

In the ASTM Method of Test for Resistance to Abrasion of Plastic Materials (D 1242)[16] specimens are mounted face down on vertical spindles and rotated under fixed load against a cast iron disk, with loose abrasive being fed continuously from a hopper. This procedure was developed at the New York Naval Shipyard and has been found useful in evaluating walkway materials for ship decks.

To eliminate the effects of specimen on the abrasive—dulling of cutting points and clogging—method B of ASTM method D 1242 is recommended (14). A series of specimens mounted on an endless conveyor belt are moved countercurrent to a continuous strip of abrasive paper 2 in. wide so that any abrasive area is used only once. Controls are provided for regulating pressure at the interface and the rate of motion. Calibration plates of chemically and physically controlled zinc are used to assure reproducible abrasion rate. A miniature version of the machine is available, which uses 1-in. wide abrasive paper; however, exact correlation of abrasion performance between the two modes has not yet been achieved. However, both machines are useful, each in its own field, and have special applications in the field of floor covering, shoe-soling materials, and similar applications involving removal of substance by abrasive action.

The continuous abrasive belt paper machines provide a solution to the problem of specimen and abrasive. In method D (D 1175) (15) the specimen is mounted on a cylinder and the abrasive paper is fed from a roll

chamber was thoroughly cleaned and the brushes were allowed to run until a good seat had been established. The zero wear measurement was then made and subsequent measurements were made every day, until a 200-hr test period had elapsed. All the brushes were run in the total absence of silicones first and then the procedure was repeated in a silicone atmosphere.

Wear measurements were taken using a micrometer held in a jig which allowed exact positioning of the brush. Measurements were taken at three positions across the face of the brush and the average reading was recorded. Fourteen readings were recorded for each wear period. A least-squares plot of the average of 14 readings as a function of time was then made to determine the wear rate. The difference in wear rate between the positive and negative brushes was generally so small that it was considered appropriate to combine these results and average 14 readings.

Figure 2 shows the wear rate of the control brush in normal and silicone atmosphere. Its wear rate is high in the presence of silicone. Figure 2 shows the wear rate of the control brush 9 months after the original data were taken using a new set of brushes and a new batch of SF96-500 silicone oil. The comparatively good agreement with the earlier data supports the hypothesis that this technique can lead to better reproducibility of results than heretofore available. The difference between the two runs can be ascribed to a number of variables which we cannot control perfectly but which, no doubt, contribute to error; variation in brush quality, variations in composition of the silicone oil, in ambient temperature and humidity, and in brush temperature, are a few. Figure 2 and subsequent graphs indicate the 95 per cent confidence limits about the average of the experimental points. It is interesting to note that the spread in the data was very high for brushes showing high wear rates in silicone but was quite small for brushes showing good wear characteristics. This is clearly shown in Fig. 3 which plots one half the confidence limit as a function of time for the brushes tested.

Figures 4 to 8 show the results obtained with the other brushes tested. In all cases, the wear rate in silicone was substantially higher than in the absence of silicone, but there were distinct differences among brushes. Three of the brushes, A, B, and C, were very poor, while D and E, were decidedly superior. Brush E showed the lowest wear rate in silicone. However, D should also be considered acceptable since its wear rate in silicone did not differ greatly from that of E. Table I summarizes the data presented in the graphs.

TABLE I.—SLOPES OF WEAR VERSUS TIME CURVES.

	Normal Atmosphere	Silicone Atmosphere
Control (A)	0.06	0.94
Control (B)	...	0.78
Brush A	0.06	1.08
Brush B	0.11	0.86
Brush C	0.09	0.75
Brush D	0.08	0.32
Brush E	0.13	0.23

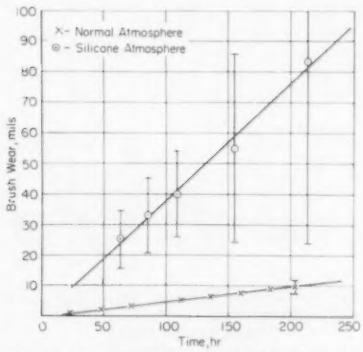

Fig. 6.—Wear of brush C as a function of time in normal and silicone atmospheres.

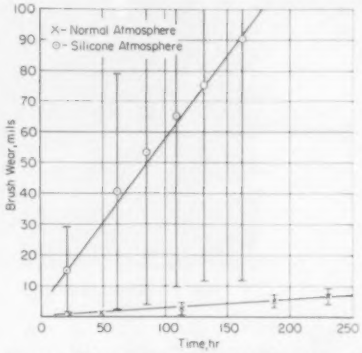

Fig. 4.—Wear of brush A as a function of time in normal and silicone atmospheres.

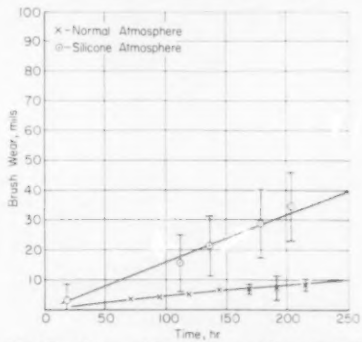

Fig. 7.—Wear of brush D as a function of time in normal and silicone atmospheres.

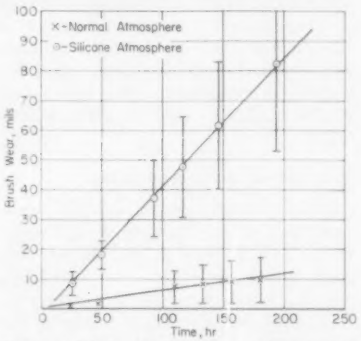

Fig. 5.—Wear of brush B as a function of time in normal and silicone atmospheres.

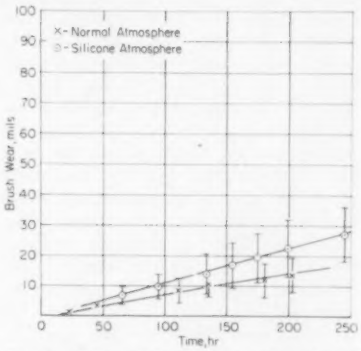

Fig. 8.—Wear of brush E as a function of time in normal and silicone atmospheres.

Acknowledgment:

The authors acknowledge helpful discussions with D. G. Flom of the General Electric Research Laboratory and L. S. Nelson of the General Electric Lamp Development Dept. The design of the test equipment was primarily the contribution of the Electromechanical Unit of the General Electric Direct Current Motor and Generator Dept.

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Hardness, Abrasion, and Wear Resistance Testing of Plastics*

BY LADISLAV BOOR

A great variety of tests for these three properties of plastics and related materials may be found in the ASTM Book of Standards. Such profusion of methods can confuse the uninitiated and even, at times, the expert. In this paper, the author reviews the methods available and discusses the interpretation and applicability of the results.

HARDNESS as an index of the resistance of a plastics substance to temporary or permanent deformation has been a useful measure of technological sufficiency in service and chemical and physical changes in processing, such as cure, state of polymerization, and reversible and irreversible degrading effects caused by temperature, light, moisture, and oxygen absorption. Wear and scratch resistance have had many interpretations each associated with a particular class of application, and with the response of the material to the specific deforming forces.

Since plastics cover an enormous range of resistance to indentation—from the consistency of freshly baked bread to that of the softer metals—a variety of instruments has been developed to measure significant differences in the respective classes of plastics.

Hardness Testing

The general term "hardness" has been defined by L. B. Tuckerman (1)[1] one of the oldest living veterans of the hardness testing field, as "a hazily conceived-conglomeration or aggregate of properties, more or less related to one another." One of the earliest systematic concepts of hardness was developed by Reamur in 1722. A steel bar, heat treated to produce a hardness gradient from dead soft at one end to glass hard at the other, was scratched with an unknown; the point on the bar at which the unknown would scratch was an index of its hardness (2). A century later, the Mohs scale of minerals was introduced—talc equal to one and diamond ten. Other forms of quantitative measures of scratching and indentation were devised in particular industries, all providing a quantitative index for some specific purpose. In 1900, J. A. Brinell developed his ball indentation test and put it on a quantitative basis—specifically for ferrous metals and alloys. It measures residual indentation made by a 10-mm ball with either of two fixed loads, and the method has since been elaborated by Meyer and others. In 1906, the scleroscope was invented and is still widely used in metals industries. Hardness of metals is measured by the height of rebound of a diamond-pointed tup falling from a fixed height.

Stanley Rockwell introduced the first models of the Rockwell tester in 1919, and in the intervening years this instrument has been refined and a "superficial" model added. It has largely replaced the other hardness testers used in the metals industry. In Europe, the Vickers diamond pyramid instrument, introduced about 1925, is widely used. In the U. S. the Knoop microhardness tester, developed at the National Bureau of Standards in 1939, is used primarily for research in microhardness of metals and alloys; the commercial version of this instrument is known as the "Tukon" (3).

Let us consider what these systems are measuring. Characteristic of all is the use of a spherical, pyramidal, or conical indenting shape made of a substance (hardened steel, carbide, sapphire, or diamond) relatively unaffected by the test material to displace or indent the test material under controlled force. The effect is measured by the dimension of the resulting displacement (diameter or depth). Hence, we can say these systems measure the resistance of a material to being pushed around.

From a physical point of view, this index of resistance is related to the modulus—the specific stress-strain relation defined in tension as Young's modulus. It has been demonstrated that, within limits, this relation holds equally well for compression; hence, the indentation of a very small portion of the material is a good index of projected behavior in tension, compression, shear, and torsion. In the case of metals subject to different heat treatments, cold work or of dissimilar metals or substances, for example steel *versus* copper, the indentation hardness would be influenced not only by modulus difference, but also by the area inclosed in the graph of unit stress plotted against deformation beyond the yield point. For example, the modulus of high-carbon steel from the annealed to the hardened condition does not change significantly from 30 million; however, the area under a curve, plotting stress against strain to the point where the total stress is exactly counterbalanced by the resistance of the progressively increasing area supporting the load, will be enormously different. Annealed high-carbon steel will test Rockwell hardness C 20; in the hardened condition it will test Rockwell hardness C 65 to 70.

In metals the resistance to indentation has been developed as a valuable index of composition, heat treatment, work-hardening properties, degree of spring, and elastic properties. Because of its simple form, rapid measurement, and the fact that the specimen is not destroyed in testing, it has a firm place in today's technology.

It was natural that when plastics began to take their place as engineering

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* Presented at the Fifteenth Annual Technical Conference of the Society of Plastics Engineers, New York, N. Y., Jan. 1959.

[1] The boldface numbers in parentheses refer to the list of references appended to this paper.

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materials, the same approach was developed to use resistance to indentation not only for its own sake but to infer other engineering properties. Let us re-examine the purpose of a hardness test and what it should tell us. There are many situations in which hardness index is sought for its own sake: for instance, to measure the indentation of a furniture caster into a slab of floor tile when loaded by a 250-lb subject, or the tooth marks of a one-year-old on a plastic teething ring, or the impression of a sharply pointed rock on a shoe sole. Such inferences from indentation hardness are straightforward.

There is also the category of tests in which identation hardness helps infer other properties such as tensile or compressive strength, or modulus. In this area great care must be taken to establish such a correlation by rigorous comparisons. Although there is a fairly useful correlation between indentation hardness of steels and nonferrous metals and their respective tensile strengths, such relations cannot be uncritically carried over to plastics without a systematic study of the correlations. It is highly probable that such inferences will apply only in a limited way to a given class of plastics.

Caution should be exercised in inferring other properties such as wear, abrasion, and mar resistance from indentation hardness tests; for example, a mar resistance test of soft plastic using falling abrasive may show it to be much better than glass by the same test (**4**).

Indentation Hardness Methods

The Brinell method using loads of 3000 and 500 kg on a 1-cm ball and measuring residual indentation by means of a magnifier was never adopted for plastics, not only because the elastic recovery, both immediate and delayed, produced no sharply defined edge of the indentation but also because the lowest load was too high for most plastics.

Although the Tukon indenter (**3**) has been used for research and exploration in anistropy, it has not received wide acceptance for general control work, principally because it measures residual identation with a microscope, which in most plastics is very time-dependent.

The Rockwell index of hardness is based on a depth of residual indentation measured directly. It was adopted sometime in the 1930's by ASTM Committee D-9 on Electrical Insulating Materials, and later was taken over by Committee D-20 on Plastics. It is currently designated as ASTM Method of Test for Rockwell Hardness of Plastics and Electrical Insulating Materials (D 785).[2] The standard long-stroke Rockwell instrument operates on the following principle: the indenters used in testing plastics are hardened steel spheres with diameters of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in. A minor load of 10 kg is imposed on the specimen and the dial is set at zero. A major load is then applied for a fixed time. The major load is then removed, the minor load remaining. After a fixed time, a reading is taken that is the increment of indentation remaining after removal of the major load on reversed scale, that is, the large numbers representing small indentations (greater hardness).

To cover the wide range of hardness in plastics, a variety of loads and indenters is used:

	Scale	Major Load	Penetrator
Low hardness...	R	60	$\frac{1}{2}$-in. ball
	L	60	$\frac{1}{4}$-in. ball
	M	100	$\frac{1}{4}$-in. ball
High hardness..	E	100	$\frac{1}{8}$-in. ball

These load-penetrator combinations will cover the range from the softer rigid materials such as plasticized vinyl plastics, to the hardest phenolic and melamine asbestos and glass-filled compounds. It should be noted that the Rockwell methods described are based on the behavior of metals in which negligible recovery occurs after indentation by the major load. This however, does not hold for many of the plastics. These relationships were studied in a variety of plastics (**5**) and it was found that many plastics recovered from the major load indentation with time. Time-indentation relationships are shown in Fig. 1. As a result of this work, method B of ASTM Method D 785 was developed for measuring Rockwell indentations *under major load*, which is called the Rockwell alpha scale. The Rockwell hardness R scale ($\frac{1}{2}$-in. ball, 60-kg major load) has been used to study mechanical properties and their dependence on temperature of polyester and vinyl plastics (**6**). Typical curves obtained by this procedure are shown in Fig. 2. The lower inflection point in these curves does not signify a sudden increase in indentation hardness but the transition to a rubbery elastic behavior evidenced by elastic recovery when the major load is removed. On the alpha scale, the readings at this point would take a sudden drop to values beyond the lower limit of the instrument.

The Barcol indenter, widely used in plastics field, is now being considered as the basis for an ASTM method. This portable spring-loaded instrument was originally designed to distinguish various alloys of aluminum. The indenter is a truncated cone with a 26-deg angle and a flat tip 0.0062 in. in diameter.

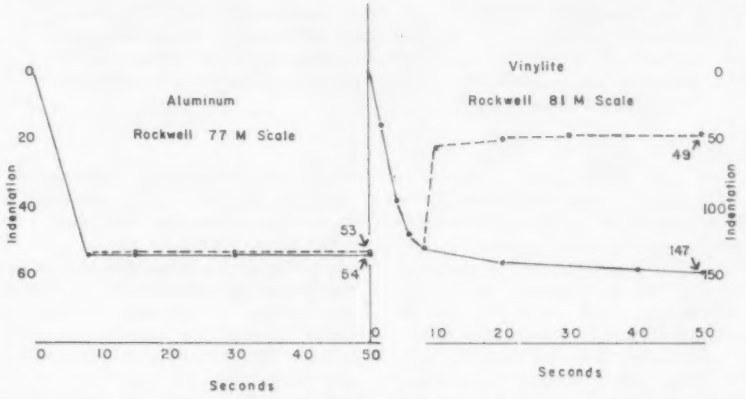


Fig. 1.—Time-indentation relationships. Rockwell $\frac{1}{4}$-in. ball, 100-kg load (M scale).

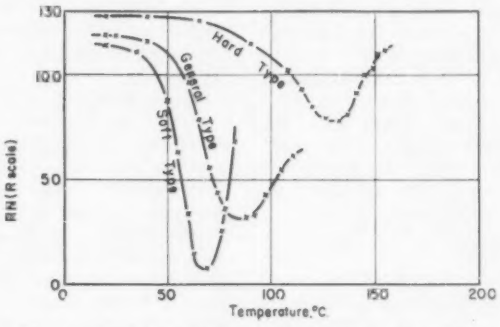


Fig. 2.—Typical curves for rigid polyester cast resins.

[2] ASTM Method of Test for Rockwell Hardness of Plastics and Electrical Insulating Materials (D 785), 1958 Book of ASTM Standards, Part 9, p. 273.

The scale reads 0 to 100 direct hardness. (See Fig. 3.)

Scratch Hardness Methods

The Bierbaum hardness tester shown schematically in Fig. 4 has also been widely used in the plastics industry (7,8). It does not measure indentation hardness directly but determines the width of a scratch made by a precisely ground point exactly loaded and drawn over the surface of a plastic. In this case, residual width is measured; a deep furrow that recovered after the scratching point had passed would be rated high on the scale. Typical Bierbaum scratch values are as follows:

Vinylidene chloride	5 to 9
Ethyl cellulose	5 to 8
Cellulose acetate-butyrate	4 to 19
Cellulose nitrate	8 to 16
Polystyrene	9 to 15
Cellulose acetate	10 to 20
Polyester, unfilled	10 to 15
Methyl methacrylate	15 to 19
Phenolic, molded	17 to 22
Melamine laminate	28 to 32
Plate glass	700 to 800

An excellent review of the history of scratch hardness measurements was made by Bernhardt (9) who also made an analysis (10) of the four variables involved in making a scratch:

1. load on indenter,
2. velocity of deformation,
3. tangential force to propagate the scratch, and
4. dimensions of displacement.

Bernhardt used a conical rounded sapphire point with a radius of approximately 100 μ. His conclusions indicate that in addition to the indenting force and the force at right angles which propagates the indentation into a groove, the coefficient of sliding friction between the specimen and the indenter is an important factor in scratch resistance.

ASTM Method of Test for Deformation of Plastics Under Load (D 621),[3] an indirect method of test, has had a long history of use in electrical insulating materials. Instead of the penetrator being smaller than the specimen, as is the case with indentation tests, the surface applying the load is larger than the specimen and the result is a compression test where the entire specimen carries the compressive load.

Two variations of Method D 621 for rigid and nonrigid plastics are in use. Method A gives the index of rigidity of plastics at service temperatures and also evaluates their ability to withstand compression in assemblies of conductors and insulators held together by bolts, rivets, and other fastening devices. Method B determines the extent to which a plastic will return to its original dimensions after being compressed.

In the very soft range comparable to the consistency of pure gum rubber in its filled and vulcanized forms, durometer A used in ASTM Method D676[4] covers the softness range from pure gum to tire-tread types of vulcanizates; model D used in Method D 1484[5] overlaps the high range of model A and includes harder compounds such as hard rubber and rigid plastics. The portable, spring-loaded instruments were developed for elastomeric and rubber-like materials, and the two methods cited above are limited to this use. Revised versions of these methods have been written making them applicable to plastics as well as rubber; the designation of the method for plastics is D 1706.[6]

The indenting points, although the same in diameter, differ in angle and sharpness, model A having a 35-deg truncated cone, a point 0.031 in. in diameter, and a maximum load of 822 g; model D has a 30-deg cone point with a 0.004-in. radius sphere on the end and maximum load of 10 lb. The Rex gage uses the same principle. All are calibrated to a direct hardness reading of zero to 100.

A dead-weight-load instrument using a 3-lb load on a spherical indenting point 0.0938 in. in diameter surrounded by a presser foot 0.625 in. in diameter with a 5-lb load used for measuring hardness in the soft range of elastomers is described in ASTM Method D 314.[7] Readings are made in direct indentation in thousandths of an inch (inverse hardness).

Fig. 3.—Barcol impressor.

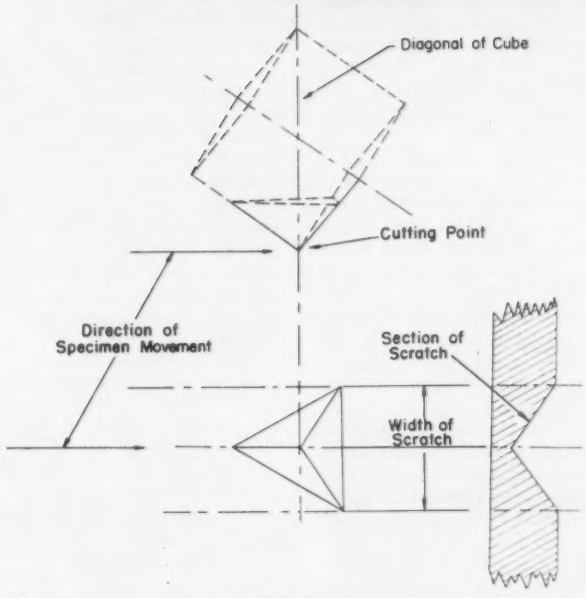


Fig. 4.—Schematic drawing of the Bierbaum Microcharacter tester.

[3] ASTM Methods of Test for Deformation of Plastics Under Load (D 621), *Ibid.*, p. 369.

[4] ASTM Method of Test for Indentation of Rubber by Means of a Durometer (Tentative) (D 676), *Ibid.*, p. 1303.

[5] ASTM Method of Test for Penetration of Hard Rubber by Type D Durometer (Tentative) (D 1484), *Ibid.*, p. 1698.

[6] ASTM Method of Test for Indentation Hardness of Plastics by Means of a Durometer," (D 1706) 1959 Supplement to 1958 Book of ASTM Standards, Part 9, p. 37.

[7] ASTM Method of Test for Hardness of Rubber (D 314), *Ibid.*, p. 1297.

Other methods with some variations in indenter load and method of mounting are also used. The instrument used in ASTM Standard Method of test for Indentation of Rubber by Means of the Pusey & Jones Plastometer (D 531)[8] has been modified by many workers, two of the best known versions being the Admiralty and Brooklyn Naval Materials Laboratory Indenter (MLI). Another similar instrument is used in ASTM Method of Test for International Hardness of Vulcanized Natural and Synthetic Rubbers (D 1415).[9] A spherical indenting penetrator 2.5 mm (0.1 in.) in diameter is used with a minor load of 30 g and a major load of 580 g. A presser foot 20 mm (0.8 in.) in diameter with a 600 to 900-g load surrounds the indenter. An electrical vibrator is used to overcome friction. This instrument has been found suitable for investigating indentation hardness in the temperature range from 200 to −80 F where other instruments were deficient at either the high or low portion of the temperature range.

Recently Carlson (11) developed a conversion formula relating the Shore and other spring-loaded instrument scales to the readings on dead-weight instruments calibrated in depth of indentation. These relationships hold only in the temperature range in which the response of the materials is instantaneous. At temperatures where the materials exhibit delayed elasticity and creep, the conversions must be corrected for specific materials.

The lowest of the hardness ranges—foams, sponges, expanded and cellular plastics and elastomers—is so low that it is not usually associated with hardness at all. In ASTM Specification and Method of Test for Latex Foam Rubbers[10] a flat circular foot 8 in. in diameter (50 sq in. in area) is used to indent a specimen at least 12 in. square. A minor load of 1 lb is used to obtain a zero reading. The specimen is then compressed to 25 per cent of its thickness and the load is observed. In other words, instead of indenting with a known load and reading depth of indentation, here we indent to a fixed value and observe the load, still using the basic relationship of load *versus* indentation.

[8] ASTM Method of Test for Indentation of Rubber by Means of the Pusey and Jones Plastometer (D 531), *Ibid.*, p. 1307.

[9] ASTM Method of Test for International Standard Hardness of Vulcanized Natural and Synthetic Rubbers (D 1415), *Ibid.*, p. 1299.

[10] ASTM Specifications and Methods of Test for Latex Foam Rubbers (Tentative) (D 1055), *Ibid.*, p. 1701.

[11] ASTM Method of Test for Mar Resistance of Plastics (D 673), *Ibid.*, p. 294.

[12] ASTM Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products by the Falling Sand Method, (D 968), 1958 Book of ASTM Standards, Part 8, p. 683.

[13] ASTM Method of Test for Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products with the Air-Blast Abrasion Tester, (D 658) *Ibid.*, p. 679.

Another valuable tool for measuring effect of compressive forces in soft materials like sponges and foams is the Schiefer compressometer (12) in which load may be varied and resulting indentation measured.

To summarize, hardness testing is a valuable, nondestructive method for classifying compounds and their relative resistance to transient and permanent deformation. It is a quick method of following changes in physical properties due to polymerization, solvent removal, phase changes and aging effects. The heart of any successful use of an indentation test is the selection of a specific procedure suited for the application, and a continual confirmation of the correctness of the indications on samples of known behavior history.

Abrasion and Wear

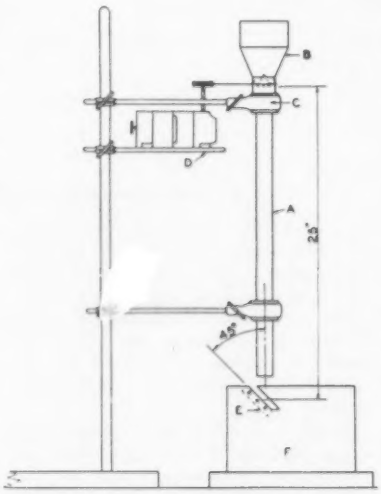
It should be pointed out that although the general concepts of hardness, abrasion, and wear are commonly associated, there is no consistent relationship between any of the indentation hardness indices and any of the aspects relating to abrasion and wear. This is inherent, first, in the various approaches to indentation hardness, such as temporary and permanent indentation and, second, in the various concepts of what constitutes abrasion and wear, how it is caused, and quantitative measures of its effects.

Many methods for measuring effects of the various forms of abrasion are available. The least severe forms of abrasion are those related to air-borne abrasive particles, such as wind-blown sand and the abrasive effects inherent in handling, stacking, and sliding of plastic surfaces such as glazing materials, optical elements, table tops, and tableware. Methods for measuring these effects are described in the following:

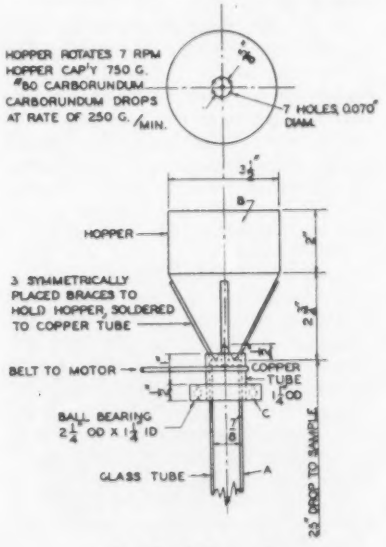
In the ASTM Method of Test for Mar Resistance of Plastics (D 673),[11] a controlled stream of abrasive particles is allowed to drop onto the surface of a plastic held at a 45-deg angle to the axis of fall (13). Effects of progressively greater amounts of abrasive are measured by means of optical properties, gloss, or transmission. (See Fig. 5.)

Closely related is the ASTM Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products by the Falling Sand Method (D 968)[12] in which a standard sand falling against a test surface is used. Its most important use has been for evaluation of protective films. In both these methods, the amount of surface material removed cannot be weighed and the quantitative effects must be judged visually, optically, or by relating the weight of abrading material to the thickness of film worn through.

In order of severity the next method is the ASTM Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products with the Air-Blast Abrasion Tester (D 658).[13] The instrument used was developed at Bell Telephone Laboratories and has an important place in the protective coatings industry and can be used for the evaluation of many plastics surfaces.



Abrader.



Details of Hopper Assembly

Fig. 5.—Schematic drawing for mar resistance apparatus (ASTM method D 673).

A stream of abrasive is blown by air pressure under exactly controlled conditions, and the abrasive effect may be measured by (1) weight of abrasive to effect removal of a coating, (2) weight of abrasive to cause weight loss of specimen, and (3) weight of abrasive as related to depth of hole worn.

The Taber abrader described in the

ASTM Method of Test for Resistance of Transparent Plastics to Surface Abrasion (D 1044)[14] tests a specimen 4 in. in diameter mounted by a center hole on a turntable which is rotated against weighted abrasive wheels. The effect is measured optically or by weight loss. A modification of the Taber abrader is used by the NEMA[15] for testing laminates in which the abrasive wheels support abrasive cloth which is renewed for each test.

In the ASTM Method of Test for Resistance to Abrasion of Plastic Materials (D 1242)[16] specimens are mounted face down on vertical spindles and rotated under fixed load against a cast iron disk, with loose abrasive being fed continuously from a hopper. This procedure was developed at the New York Naval Shipyard and has been found useful in evaluating walkway materials for ship decks.

To eliminate the effects of specimen on the abrasive—dulling of cutting points and clogging—method B of ASTM method D 1242 is recommended (14). A series of specimens mounted on an endless conveyor belt are moved countercurrent to a continuous strip of abrasive paper 2 in. wide so that any abrasive area is used only once. Controls are provided for regulating pressure at the interface and the rate of motion. Calibration plates of chemically and physically controlled zinc are used to assure reproducible abrasion rate. A miniature version of the machine is available, which uses 1-in. wide abrasive paper; however, exact correlation of abrasion performance between the two modes has not yet been achieved. However, both machines are useful, each in its own field, and have special applications in the field of floor covering, shoe-soling materials, and similar applications involving removal of substance by abrasive action.

The continuous abrasive belt paper machines provide a solution to the problem of the effect of the test material on the abrasive. Many of the plastics develop local temperature gradients when abraded, causing softening or melting and consequent blocking or gumming of abrasive surfaces. In the case of loose abarsive, the plastic test surface may be impregnated with abrasive particles and thus become an abrasive lap and wear away the cast iron turntable.

Other abrasion testers, developed particularly for textiles but useful for testing abrasion of film materials and plastic coatings on fabrics, are described in the ASTM Method of Test for Abrasion Resistance of Textile Fabrics (D 1175).[17]

In method A—the Inflated Diaphragm Method (D 1175) (15) the instrument developed by R. G. Stoll for the Army Quartermaster Corps is used. The specimen is stretched by means of an inflated diaphragm, and a precisely loaded abrasive surface oscillates while the specimen rotates slowly.

The well-known Wyzenbeek tester is used in method C—the Oscillatory Cylinder Method (D 1175). Strips loaded and under tension are abraded by an oscillating quadrant of a cylinder coated with abrasive cloth (16).

The instrument used in method E—Uniform Abrasion Testing Machine Method (D 1175) was developed at the National Bureau of Standards by Herbert F. Schiefer. Both the specimen and abradant rotate. The abradant may be in the form of a grid of hardened steel or any standardized sheet abrasive medium (17,18).

Summary

The analysis and determination of the nature of the abrasive action under investigation is of utmost importance with the selection of the test apparatus which most closely simulates the abrasive effects under study. A series of comparisons between specimens of known relative abrasion behavior will indicate whether the abrasive condition is being simulated by the test instrument.

Acknowledgment:

I wish to acknowledge the generous assistance of the many contributors, especially Vincent Lysaght of the Wilson Mechanical Instrument Co., Bruce Lewis of Tinius Olsen Co., Mr. Novotny of Custom Scientific Co., Herbert Schiefer of the National Bureau of Standards, Charles L. Schuettler of the American Instrument Co., Paul Gardner of the Gardner Laboratories, to J. B. DeCoste of the Bell Laboratories and the many other companies who contributed technical data.

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[15] NEMA Standard for Laminated Thermosetting Decorative Sheets, Method of Test for Resistance of Surface to Wear, Publication No. 48-136, Oct. 1948, National Electrical Manufacturers Assn., 155 E. 44th St., New York 17, N. Y.

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Improved NBS Abrasive Jet Method for Measuring Abrasion Resistance of Coatings

By A. G. ROBERTS

A description is given of the many improvements made in the NBS Abrasive Jet Method since publication of the original article describing this rapid, reproducible, and versatile means for measuring the abrasion resistance of organic and other coatings.

A VARIETY OF improvements have been made in the apparatus and techniques used in the Abrasive Jet Method (AJM) since publication of its original description (1).[1] Of the various test methods to which reference was made in the original article, and among more recent methods (**2**, **3**, **4**), the Abrasive Jet Method is most similar in principle to the Air Blast Abrasion Tester,[2] inasmuch as both these methods accomplish the abrasion through the impingement of gas-propelled abrasive particles against the coating surface. The apparatus and techniques employed are, however, quite different.

The Abrasive Jet Method utilizes a jet of fine abrasive particles, under closely controlled conditions of flow, pressure, distance, and angle, to abrade through the coating to the substrate in a timed operation. The first show of bare substrate is taken as the end point and is usually clearly evidenced visually by an abrupt change in color or gloss. Abrasion resistance is ordinarily expressed in terms of time (seconds) per unit thickness of coating; however, coatings of similar thickness may be intercompared on the basis of total abrasion time. Very good reproducibility is obtained. The small scale of operation permits the economical use of a continually fresh (and readily available) abrasive and allows a large number of replicate tests on a single panel, so that use of a reference panel for standardization purposes is entirely feasible. The comparatively high speed of the abrasive jet particles provides a rapid rate of abrasion that permits most coatings to be tested in a matter of seconds. The abrading conditions can be readily varied over a wide range to enable the testing of virtually any type of coating. The equipment used is not complex, and many of the component parts are available commercially.

The present paper, in addition to setting forth improvements in apparatus and procedures, also discusses important operational factors that should be borne in mind by those contemplating the construction and use of similar equipment.

Improvements in Apparatus

In the basic AJM apparatus—a specialized adaptation of the S. S. White Airdent drilling machine[3]—abrasive particles sifting through holes in the floor of a vibrating storage chamber are swept from the lower chamber by a stream of carbon dioxide gas, under controlled pressure, toward a nozzle which directs the particles in a jet against the surface of the test specimen. A solenoid valve between the abrasive storage chamber and the nozzle provides positive on-off control of the gas-abrasive flow. The specimen and nozzle are mounted in a brass chamber having a front door and a top of transparent plastic. Means are provided for accurate adjustment of nozzle-to-coating dis-

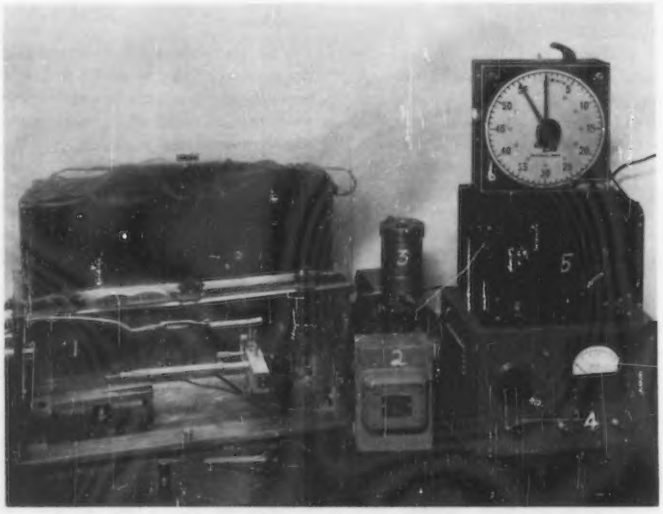

Fig. 1.—Abrasive Jet Method apparatus.

1—abrasion chamber; *2*—solenoid valve; *3*—abrasive storage chamber upon vibrator assembly; *4*—control box; *5*—electronic contact indicator; *6*—electric timer

NOTE—DISCUSSION OF THIS PAPER IS INVITED, either for publication or for the attention of the author or authors. Address all communications to ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa.

[1] The boldface numbers in parentheses refer to the list of references appended to this paper.

[2] Standard Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products with the Air Blast Abrasion Tester (D 658–44), 1958 Book of ASTM Standards, Part 8, p. 679.

[3] S. S. White Dental Manufacturing Co., 211–217 South 12th St., Philadelphia 5, Pa.

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tance and abrading angle. Spent abrasive particles are exhausted from the test chamber by an ordinary vacuum cleaner connected into one end of the chamber. The abrasion operation originally was timed with a stop watch. The abrasive flow (quantity of abrasive leaving nozzle per unit time) was controlled by regulating the voltage applied to the vibrator with a rheostat.

Recent changes in the method have not altered the basic mode of operation but have significantly improved the speed, ease, and precision of the measurements. The modified abrasion test apparatus is shown in Fig. 1. A diagram of the apparatus showing the abrasion set up and associated electrical circuits is given in Fig. 2 A description of the changes that have been made is given in the following sections.

Abrasive

Instead of the aluminum hydrate powder originally employed, the abrasive now used is the readily available S. S. White Airdent Cutting Powder No. 1. This is described by the manufacturer as an aluminum oxide powder having an average particle size of 27 μ and containing only a small proportion of particles smaller than 10 μ or larger than 53 μ (270 mesh). It is a more free-flowing powder than the aluminum hydrate and has yielded more uniform results.

Abrasive Storage Chamber

In the original storage chamber, the abrasive sifted through a ring of small holes into a circular lower chamber, the pressure between upper and lower chambers being kept equalized through a standpipe in the center. The carbon dioxide gas left the lower chamber through a hole at right angles to the entrance hole. This resulted in an undesirable tubulence that affected uniformity of flow and possibly altered, through collision, the cutting characteristics of the abrasive particles.

The chamber has now been redesigned so that the abrasive sifts into a transverse, tubular lower compartment through holes (0.022 in. in diameter) arranged in a straight line. Gas entering at one end of the tube propels the powder in a single direction along the tube and out the other end. Turbulence and interference effects are thus minimized. The pressure-equalizing standpipe is now located at the gas inlet end of the tube.

Control of Vibrator Amplitude

Close control of the amplitude of vibration is essential for maintaining a uniform flow of abrasive and a constant rate of abrasion. It has been necessary to use a voltage regulator between the abrasion equipment and the a-c line to achieve the required uniformity. The regulated line voltage is applied to the vibrator through a variable transformer which controls the amplitude of vibration.

The amplitude of vibration is also affected by the amount of abrasive in the storage chamber, since the weight and level of the powder affect the center of gravity of the electro-mechanical system. The change in amplitude (and abrasive flow) is gradual and can be compensated by periodic adjustment of the applied voltage. The powder level should usually not be allowed to drop below the half-full mark, because at the lower powder levels the mode of vibration often undergoes a pronounced change, becoming unstable and difficult to control.

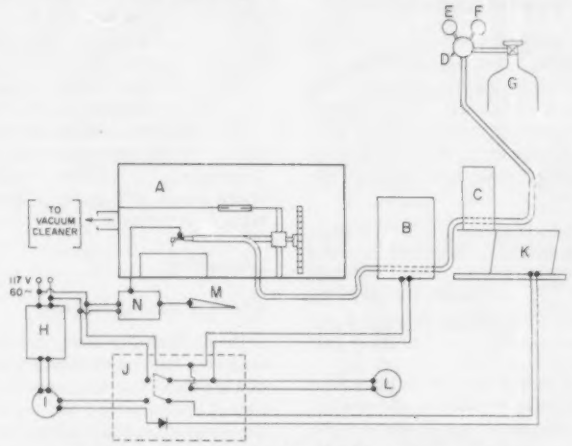

Fig. 2.—Diagram of Abrasive Jet Method apparatus.

A—Abrasion chamber; *B*—solenoid valve; *C*—abrasive storage chamber; *D*—pressure-regulating pneumatic valve; *E*—regulated pressure gage; *F*—tank pressure gage; *G*—carbon dioxide tank; *H*—voltage regulator; *I*—variable transformer; *J*—control box, with DPST switch for simultaneous operation of solenoid, vibrator, and timer; *K*—vibrator; *L*—timer; *M*—taper gage for setting distance; *N*— electronic contact indicator.

Setting Nozzle-to-Coating Distance

Use of the graduated taper gage for setting the nozzle-to-coating distance has been simplified and the accuracy improved by using an electronic device to indicate contact between the gage and the tip of the nozzle. (We now use the nozzle as purchased, without grinding the tip flush with its housing; this results in better collimation of the abrasive jet and also simplifies the calibration procedure.) Nozzle and gage are now part of a low-current electronic circuit that utilizes a thyratron relay circuit of conventional design. Contact between gage and nozzle closes the external circuit and lights an indicator lamp. With this arrangement, distance is easily set to within 0.002 in. of the desired value.

Greater speed and convenience in setting the nozzle-to-coating distance has been provided by the addition of a simple, fine-adjusting device in the form of a rod and turnbuckle fastened between the top of the center post supporting the nozzle assembly and one end of the test chamber. A slight deformation of the mounting post alignment by light tightening or loosening of the turnbuckle results in considerable downward or upward motion of the nozzle tip with negligible change in angle because of the relatively large radial distance (approx. 10 in.) from post to nozzle. Large changes in nozzle-to-coating distance, such as those required when substrates of different thicknesses are involved, are made by adjusting the large nuts on the threaded mounting post, as in the past.

Timing

Timing of the abrasion operation is now accomplished by a clock-timer that is electrically connected to the main on-off switch. Operation of this switch simultaneously controls the vibrator, solenoid valve, and clock.

Other Equipment Changes

A fluorescent light has been mounted over the transparent top of the chamber. A curtain of opaque plastic film prevents the light from shining into the eyes of the operator.

The swirl of spent abrasive particles in the test chamber eventually causes some abrasion of the surface of the transparent plastic door and top, reducing the transparency. To provide for maximum visibility in observing the end point, an elongated hole has been cut in the top of the test chamber, from which the entire abrasion process is easily and clearly viewed. The vacuum exhaust applied to the chamber prevents any escape of powder from the viewing hole.

To eliminate the undesirable planetary motion of the nozzle formerly present when the angle-setting wheel was rotated, the nozzle and handpiece assembly has been mounted in a metal

sleeve that is coaxial with the wheel, thus greatly reducing the change in the nozzle-to-coating distance with change in angle.

When test specimens are of a size different from the 2-in. width—length is not critical—for which the regular clamping arrangement was designed, the clamps can be removed and the specimen held firmly against the mounting plate by use of one or two large paper clips of the conventional flat-spring type.

Improvements in Procedure

Standard Operating Conditions

A wide range of operating conditions and abrasion rates are possible, the choice depending on the nature of the material to be evaluated. The following standard operating conditions have been adopted as well suited for the type of organic coating materials usually encountered:

Nozzle-to-coating distance	0.40 in.
Abrading angle	90 deg
Gas pressure	50 psi
Abrasive flow	5 g per min (approx.)
Temperature	23 deg Cent (73.4 deg Fahr)
Relative humidity	50 per cent

The above conditions have permitted the testing and resolution of coatings having a wide spectrum of abrasion resistance, in which the best materials were over one hundred times more abrasion resistant than the poorest. Control of temperature and relative humidity, while desirable for maximum accuracy and precision, is not essential under ordinary room conditions.

Reference Panel

The reliability of the measurements has been significantly improved by use of a reference panel to provide an overall check on the adjustment and operating stability of the equipment. The reference panel consists of a vinyl chloride plastic film, 4.5 mils (0.0045 in.) in thickness, bonded with a very thin coat of poly(vinyl butyral) to an aluminum alloy substrate. Its uniformity was established by a large number of replicate tests. Under the standard conditions referred to above, 53 sec are required to abrade through this film to the metal; that is, the abrasion resistance of the reference panel is approximately 12 sec per mil.

The reprodubility of measurements made under the standard operating conditions on the reference panel has been determined on several occasions. The coefficient of variation was found to be consistently below 2 per cent.

The reference panel is run at least once, more often if doubt exists, with each specimen tested. If large deviations from the normal rate of abrasion are noted, the abrasive flow is increased or decreased by adjusting the vibrator voltage to restore the reference value. Small deviations from the reference value are compensated by applying a linear correction factor to the observed abrasion time rather than by readjusting the flow.

Use of the reference panel provides a more convenient and reliable criterion of proper adjustment than does measurement of the abrasive flow. Occasional measurement of the flow is desirable, however. This is quickly accomplished by allowing the abrasive to flow for 15 sec into the weighing tube provided with the equipment. It will be found that when the apparatus has been adjusted to yield the 53-sec reference value on the standard panel, the flow will be well within ±0.5 g per min of the 5 g per min specified for standard conditions.

The abrasion resistance values recorded for the reference panel provide a means for reducing data obtained at different times and under different conditions to a common basis of comparison.

Discussion

Effects of Varying Pressure

It has been observed that the flow of abrasive, while essentially independent of gas pressure so long as sufficient pressure exists to sweep the particles from the lower tube of the vibrating chamber as fast as they sift into it, is very sensitive to *changes* in pressure that occur while the abrasive is flowing. A change of less than 1 psi will cause a noticeable momentary change in the quantity of abrasive leaving the nozzle. The magnitude of this momentary change in flow depends not only on the extent of the pressure change but also on the *rate* at which it occurs. Thus, even very small fluctuations in pressure, if abrupt or rapid, will result in significant variations in abrasive flow. Under these conditions a decreasing pressure is accompanied by an increased flow.

The explanation for the effect of varying pressure lies in the momentary pressure differential that exists between the upper and lower compartments of the vibrating storage chamber before pressure equalization can take place through the interconnecting standpipe. Changes in the gas pressure first appear in the lower compartment, into which abrasive powder is sifting. A rapid decrease in pressure momentarily produces a significant pressure head in the upper chamber, resulting in a momentarily increased sifting rate. A rapid increase in pressure reverses the pressure head, resulting in a momentary reduction in the sifting rate.

The foregoing also serves to explain why the initial flow of powder is always visibly greater than the subsequent steady flow. We have established by experiment that each time the equipment is switched on, approximately a 0.25-g increment of abrasive sifts into the gas stream, even when the vibrator is completely cut off. Switching the equipment through several on-off cycles with zero voltage to the vibrator, while monitoring the abrasive flow with the weighing tube, causes multiples of the basic powder increment to accumulate in the tube. Evidently, the increment is primarily the result of a momentary drop in lower-chamber pressure at the instant of switching on.

This initial increment of powder is of practical importance when making successive abrasion determinations on specimens with short abrasion times, for example, 2 or 3 sec. The short-term on-off cycling may build up larger quantities of abrasive powder in the system than are swept out during the testing interval, rendering the results doubtful or meaningless, or even causing sporadic clogging of the abrasive flow lines. This difficulty can be alleviated by operating the equipment for 10 to 15 sec between replicate tests on specimens with very short abrasion times, so as to ensure uniform flow.

A better and very reproducible procedure for specimens having short abrasion times is the following: The specimen is clamped and the nozzle-to-coating distance is adjusted in the usual manner. A dummy panel is placed—not clamped—over the test specimen to shield it from the initial abrasive flow. The equipment is switched on as usual to start the flow and the timer. After a definite time interval (10 sec is satisfactory), and while the abrasive is flowing, the dummy panel is removed to expose the surface of the test panel. Opening the door to the abrasion chamber to remove the dummy panel does not interfere with the test.

Coating Thickness

The abrasion time determined by the Abrasive Jet Method for a given material is practically proportional to thickness up to about 5 mils (0.005 in.) but increases more rapidly for thicknesses greater than 5 mils. This departure from linearity at the greater thicknesses probably arises largely because the abrading action is hindered by the interference of particles in the pit formed during the course of the abrasion. Abrasive particles trapped in the bottom of a deep pit could shield the coating surface from abrasion. In tests at a 45-deg angle of abrasion, the abrasion often results in an undercut hole in which the effect of thickness is particularly noticeable.

Practical Operating Limits

Although a very wide range of operating conditions and associated abrasion rates is available, so that significant differences in abrasion resistance among almost any coating materials can be re-

solved, it will usually be found desirable in the interests of maintaining reasonably good precision to stay within the following operating limits:

Nozzle-to-coating distance	0.1 to 0.6 in.
Abrading angle	30 to 90 deg
Gas pressure	30 to 60 psi
Abrasive flow rate	3 to 7 g per min
Voltage to vibrator	50 to 130 v

A brief discussion of the factors determining these limits will provide information that may be helpful in dealing with unusual materials or erratic operating conditions. Thus, the upper limit of useful nozzle-to-coating distance is reached when the jet becomes too diffuse to yield sharp end points, while the lower limit is determined by the larger setting errors and the introduction of unevaluated turbulence effects. Abrading angles less than 30 deg, besides being inconvenient to work with, do not afford any further increase in the rate of abrasion (the curve representing the dependence of abrasion time on abrading angle (1) goes through a minimumi n the region of 30 deg). Low gas pressures result in nonuniform abrasive flow and make the system prone to clogging; unnecessarily high pressures result in needless, excessive wear on the nozzle. (The nozzle has become worn to an extent requiring its replacement when the round end point normally observed in perpendicular abrasion acquires an oval or keyhole shape.) When the flow of abrasive is very small, the abrasion results tend to be inconsistent, partly because the low amplitudes of vibration involved are obtained at voltages that do not operate the vibrator reliably. Flows greater than those recommended waste abrasive, since beyond a certain point the larger abrading potential of an increased number of particles is offset by the reduction in their kinetic energy as a result of increased interference among them. Although not listed in the above table, the level of powder in the storage chamber should not be allowed to drop below the half-full mark, for reasons already given in the section on Control of Vibrator Amplitude.

Applications

The Abrasive Jet Method has been applied successfully to measurement of the abrasion resistance of organic coatings on metal, wood, plastics, and other rigid substrates, and also to such materials as porcelain and anodic coatings (5). Recently, it was advantageously employed to measure the abrasion resistance of plastic film and tape attached with adhesive tape to a metal substrate.

Although this test is most convenient and precise when applied to smooth, uniform coatings on flat substrates, it is not restricted to such specimens. Coatings with an irregular, textured surface, which give a wide spread of values, may be evaluated by making a sufficient number of tests per panel to ensure a valid statistical sample for computing a reliable average value. If necessary, 50 or more tests can be made on a single 3 by 6-in. panel without seriously crowding the test areas. Curved or irregularly shaped objects also can be suitably positioned for testing.

The abrasive jet can be used to abrade sheet metal. The specimen should be mounted on a contrasting substrate to achieve a clear end point. Aluminum, brass and steel are abraded at rates of the same order of magnitude as are the more resistant types of organic coatings.

The basic function of the Abrasive Jet Method could be inverted to yield information on the abrading qualities of various abrasives.

Possible Future Modifications

The present AJM apparatus is the outgrowth of a step-by-step development to improve precision and ease of operation. As often happens in a development of this kind, the much-modified end product, while quite satisfactory, is not necessarily the best possible mechanical arrangement. If another abrader were to be constructed, several improvements could be made. Chief among these would be separation of the abrasion chamber from the associated controls used to position the nozzle vertically, horizontally, and angularly. Such a separation of function would keep abrasive particles out of the threads and joints of the adjusting controls and would permit use of a rack and pinion assembly for convenient and rapid adjustment of both the gross and fine setting of nozzle-to-coating distance.

The Abrasive Jet Method could be adapted for high- or low-temperature measurements by separating abrasion and control functions as suggested above and providing an insulating jacket and thermal control for the abrasion chamber itself. For measurements at high temperatures, the transparent top could be made of quartz or glass.

With the improved apparatus and procedures described, the coefficient of variation of AJM measurements on the reference panel is consistently less than 2 per cent. The chief remaining source of variation is the fluctuation in abrasive flow resulting from the inherent instability of the electro-mechanical vibrator system and from the changes in the geometry of the system as the level of powder changes. It is possible that a radically different type of abrasive feed system could be developed that would give better precision while requiring less monitoring and adjusting.

Summary

A description is given of the improvements that have been made in the apparatus and procedures of the NBS Abrasive Jet Method since publication of the original article describing this means for measuring abrasion resistance. Improvements include (1) use of a more free-flowing abrasive, (2) a redesigned abrasive sifting chamber to minimize turbulence and interference effects, (3) greater uniformity of abrasive flow by control of amplitude of vibration through a variable transformer and regulated line voltage and by attention to the geometry of the system, (4) an electronic contact device for greater speed and precision in setting nozzle-to-coating distance, and (5) automatic timing.

Precision is greatly improved by use of a reference panel to provide an over-all check on equipment adjustment and a means for reducing data obtained under different conditions to a common basis of comparison.

The effects of coating thickness and varying pressure on the abrasion results are discussed. Practical operating limits are defined. The method is not limited to the organic coating materials for which it was originally designed but is also applicable to ceramic, porcelain, and anodic coatings. Films and tapes may be tested by first attaching them to a rigid substrate.

Mention is made of some possible future modifications in the apparatus relating to improved mechanical arrangement and high-temperature applications.

Acknowledgment:

The support of the Bureau of Aeronautics, Department of the Navy, during a major portion of the developmental work described is gratefully acknowledged.

The author appreciates the assistance of Alan R. Quasius, who obtained much of the data and contributed valuable ideas toward the improvement of the apparatus and procedures.

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Machining of Notched Tension Test Specimens

By J. L. MARCH,[1] W. J. RUPRECHT,[1] and GEORGE REED[1]

A procedure that has been found satisfactory for preparing notched tension specimens is given in detail. When specimens of annealed AISI 4300 series steels are machined in quantity (25 or more) processing time is reduced to 1 man-hour per specimen.

CERTAIN high-strength metals and alloys are being used in structures where they may fail in a brittle manner due to their inability to tolerate small flaws. In such cases, failure may occur well below the design stresses based on the yield strength of the material.

To judge this property in thin gages of metals, one method uses a notched tension specimen. In the Report of the ASTM Committee on Fracture Testing of High-Strength Sheet Materials[2] a description is given of the notched tension specimen developed by the National Aeronautics and Space Administration (NASA). This paper describes a procedure for the machining of the NASA-type notched tension specimens in which the required close tolerances and notch geometry are consistently maintained. Starting with 2 by 8-in. coupons of sheet thickness, machining is accomplished in four operations:

1. Milling of the reduced section on a vertical milling machine,
2. Machining of loading pin holes on a vertical jig borer,
3. Rough machining of notches to within 0.005 in. of finished depth using a horizontal milling machine and a 60-deg cutter, and
4. Finish machining of notches using a vertical jig borer and drawing a 59-deg carbide cutter bit across the root of the notch to produce a root radius less than 0.001 in.

Specially designed holding fixtures are used to position the specimens on the machine, and precision dial indicators and optical instruments are used to insure accurate alignment during machining. The notch root radius is checked on an optical comparator at 100× magnification. With the exception of the final notching operation, the specimens were processed in multiples of four for 0.095-in. sheet thickness and two for 0.220-in. thickness. The procedure was developed on annealed AISI 4300 series steels, and when as many as 25 specimens were processed at a time the machining time was 1 man-hour per specimen.

Description of Specimen

A drawing of the NASA-type notched tension specimen is shown in Fig. 1. This specimen was designed to minimize loading eccentricity. The longitudinal centerline of the specimen coincides with the pin hole centers within 0.001 in., and the notches are positioned symmetrically to the specimen centerline, to within 0.001 in. Pin loading minimizes bending moments in the sheet plane which originate from misalignment of the specimen grips during loading.

Whenever possible, the specimens are prepared from annealed sheet, and in cases where the material to be tested is in the heat-treated condition, extreme care must be taken in preparing the notches to prevent inducing small cracks at the notch root which would produce erroneous results.

Preparation of Specimen

The specimen blanks are 2 by 8 in. with edges surface-ground to permit accurate end and side alignment in the machining fixtures. The machining procedure can be divided into the following four operations.

Milling Reduced Section

The specimens are positioned on a special fixture and machined in a vertical milling machine using a 2-in. diam-

NOTE—DISCUSSION OF THIS PAPER IS INVITED, either for publication or for the attention of the author or authors. Address all communications to ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa.

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[2] See p. 18 of this publication and ASTM BULLETIN, No. 243, Jan , 1960, p. 29.

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eter fluted end mill. The fixture is bolted to the table of the milling machine, and both sides of the specimens are machined in the same setup. The fixture has a contoured relieved section on each side $\frac{3}{8}$ in. deep and slightly larger than the cut-out section of the specimen when the operation is completed. The specimen is positioned longitudinally against a stop on the fixture, and a 4-in. dial indicator is used to set and measure table travel, thereby assuring proper alignment and parallel reduced section surfaces. A drawing of the fixture is included as Fig. 2, and a photograph of the setup on the milling machine is shown in Fig. 3.

Machining Pin Holes

A special fixture incorporating an end stop and two side stops is used to position the specimens; machining is done on a vertical jig borer. The fixture is positioned on the table of the jig borer so that the true centerline of a specimen clamped in the fixture is within 0.001-in. alignment with the spindle post. The spindle is centered over the reduced section of the specimen using a test indicator with 0.0001-in. divisions. The holes are drilled to $\frac{63}{64}$-in. diameter and then finish bored with a preset boring tool to 1.000 +0.0005–0.0000 in). A drawing of the fixture is included as Fig. 4, and a photograph of the setup for pin hole boring is shown in Fig. 5.

Rough Machining of Notches

The notches are rough machined to within 0.005 in. of the finished depth on a horizontal milling machine using a regular 2-in. diameter 60-deg milling cutter. A pin fixture used to locate and hold the specimens is equipped with a hold-down plate that has oversize notches milled in the edges to give as much support as possible to the specimens during machining. The milling cutter is centered over the fixture centering line with a binocular microscope, and during machining the notch depth

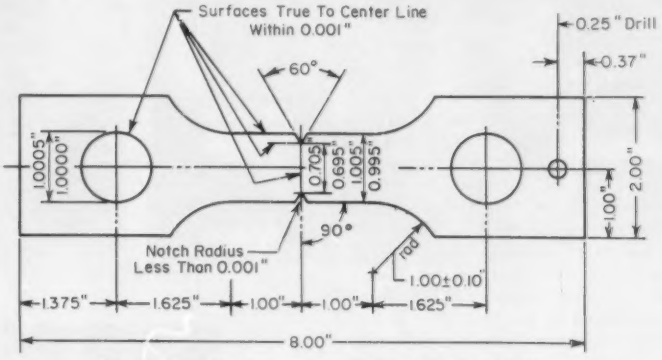

Fig. 1.—Notched tension specimen (sheet and plate).

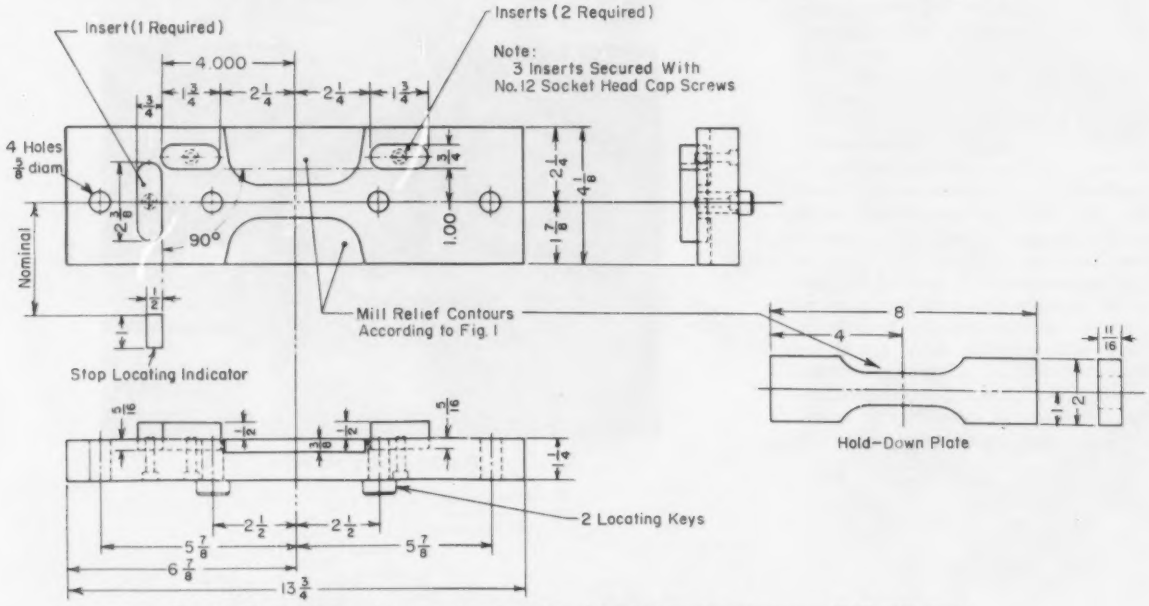

Fig. 2.—Fixture for machining reduced section of notched tension specimens (SAE 1020 steel).

NOTE.—For dimensions not specified see Fig. 1.

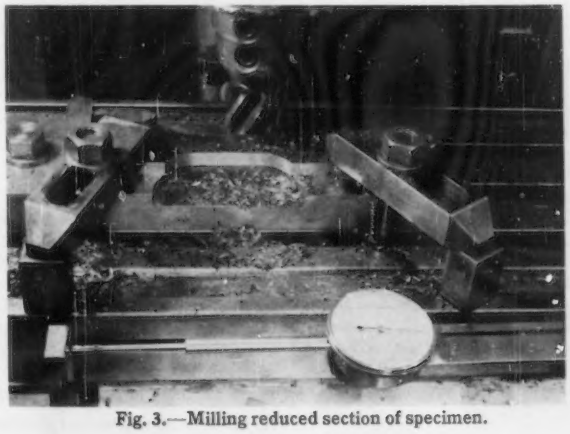

Fig. 3.—Milling reduced section of specimen.

is checked with a point indicator depth micrometer. To machine notches on the opposite side of the specimens, the hold-down plate is unbolted and the specimens are reversed. A drawing of the fixture is shown in Fig. 6, and a photograph of the rough notching setup is shown in Fig. 7.

Finish Machining of Notches

In each operation to this point, the 0.220-in. specimens are machined in pairs and the 0.095-in. specimens are machined four at a time. For finish machining of the notches, the specimens are broached individually on a jig borer using the same fixture that was used for boring the pin holes (Fig. 4). A 59-deg carbide cutter bit is mounted in the spindle and locked in position after it has been centered with the specimen notch. Using a 0.0005-in. cross feed, the notch is finished by drawing the cutter bit across the notch root. After machining each notch, the radius of the cutting tool is checked for wear with an optical comparator at 100× magnification. In practice, one to four notches were cut before a tool required sharpening.

The 59-deg angle on the cutter bit allows a minimum of metal removal to produce a notch radius less than 0.001 in. The notch radii are checked on an optical comparator at 100× magnification, and the specimen width between notches is measured by locating the apex of the notches with a centering microscope mounted on the spindle of the jig borer and recording table travel between the notches. Figure 8 is a photograph of the finish notching operation, and Fig. 9 shows the centering microscope mounted in position on the jig borer spindle.

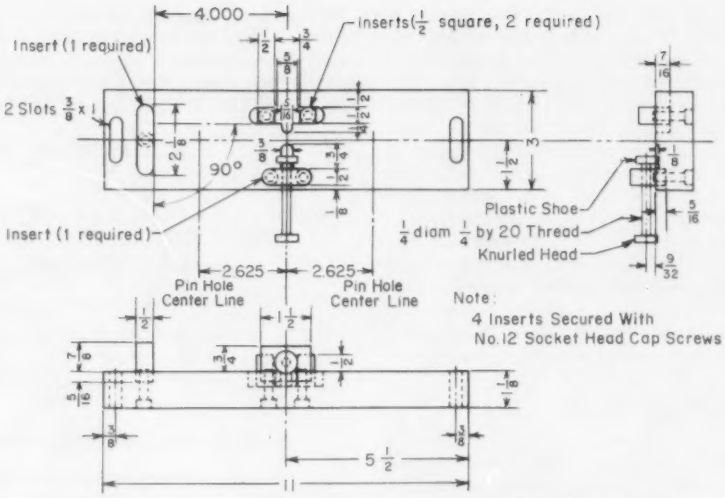

Fig. 4.—Fixture for boring pin holes and finish notching of notched tension specimens (SAE 1020 steel).

NOTE.—For dimensions not specified see Fig. 1.

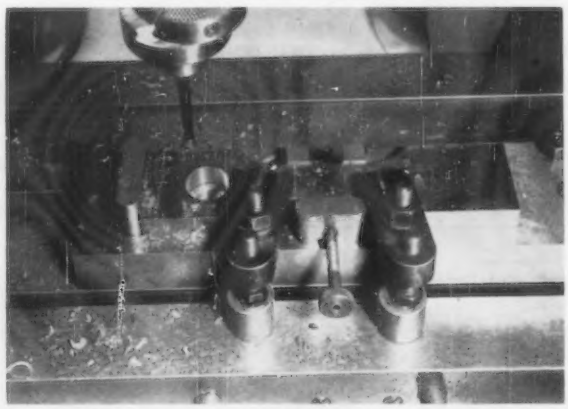

Fig. 5.—Boring pin holes.

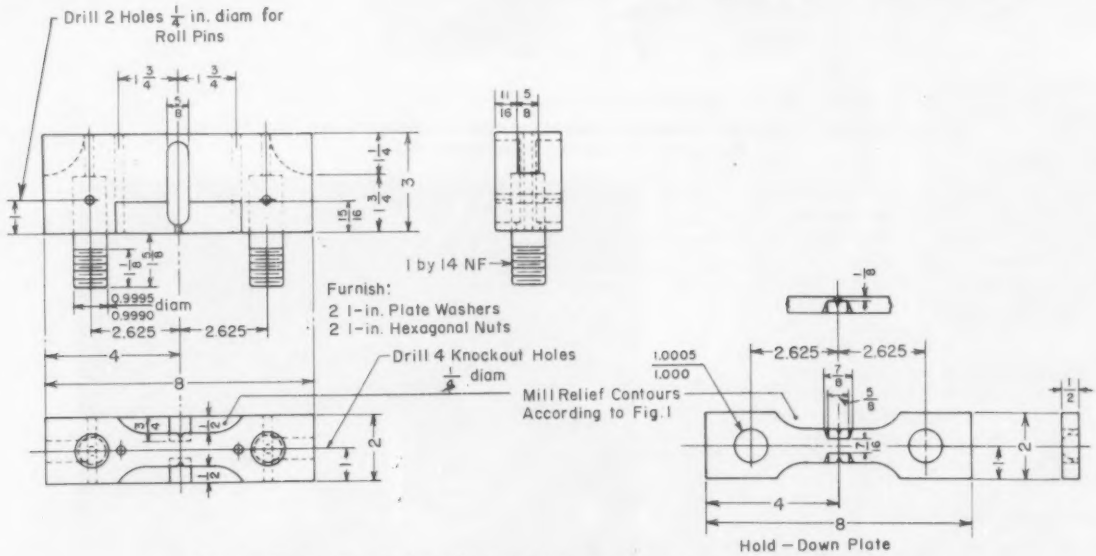

Fig. 6.—Fixture for rough notching of notched tension specimens (SAE 1020 steel).

NOTE.—For dimensions not specified see Fig. 1.

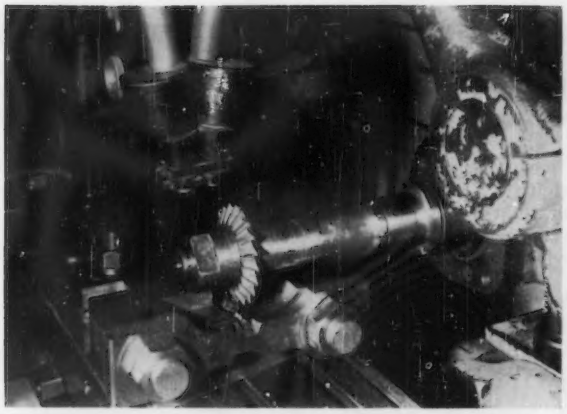

Fig. 7.—Rough notching.

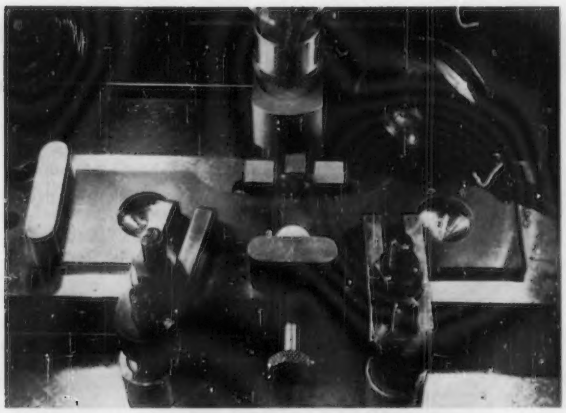

Fig. 8.—Finish notching.

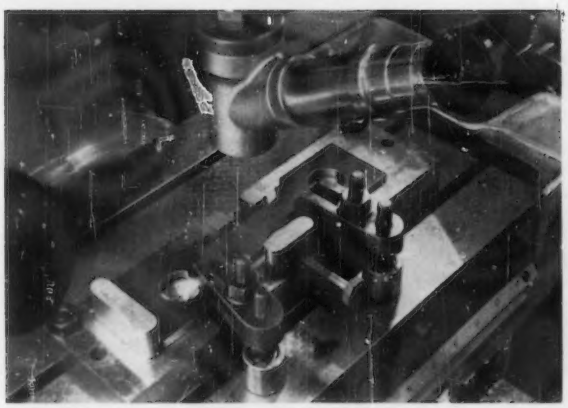

Fig. 9.—Inspection of specimen width after notching.

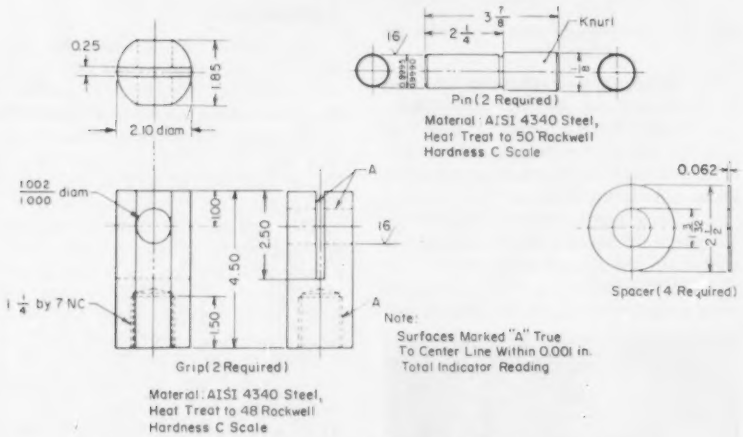

Fig. 10.—Pin-type specimen grip for notched tension specimens.

The 59-deg cutter bit was sharpened on a Heald style No. 1 automatic tool sharpening machine. The tool design incorporated zero top and back rakes, a 2-deg primary side rake, and a 7-deg secondary side rake. Production sharpening rate amounted to 5 min for each cutter bit.

Description of Specimen Grip

A drawing of the special pin-type specimen grip is shown in Fig. 10, and a photograph of one of the completed grips is shown in Fig. 11. Standard spherically seated holder rods, which aid in alignment of the grips during loading, are used with the pin grips. Also, the honed surface of the pin plus the maximum allowable variation of 0.0015 in. between pin diameter and specimen pin hole diameter insure minimum misalignment of the specimen during testing. As further assurance of proper alignment, a shim is placed on each side of the specimen to allow a total of approximately 0.020 in. clearance in the pin grip slot during loading.

Conclusion

This procedure has been utilized in preparing approximately 100 specimens which were tested after heat treatment to yield strengths ranging from 140,000 to 225,000 psi. The reproducibility in duplicate or triplicate specimens was considered exceptional for notch tension testing.

With holding fixtures of the types described, the operational techniques can be performed by a skilled machinist not having special training in the preparation of notched tension specimens.

Fig. 11.—Pin grip for loading.

Acknowledgment:

The authors are grateful for the assistance and cooperation of W. F. Brown, Jr., of the Lewis Research Center, National Aeronautics and Space Administration.

Technical Note—Testing Machine Attachment Permits Straightness Measurements on Fine Wire

STRAIGHTNESS IS an important criterion in selecting ultrafine tungsten and molybdenum bare and plated wire for use in electronic tubes. For example, it is of utmost importance where filamentary wires must be fed through small openings; also, in grid and coil winding applications, poor straightness characteristics may contribute to uneven spacing of the windings. One of the aims of ASTM Methods F 219[1] is, of course, to recommend a technique which can be used as a standard method for straightness measurements. However, although the testing procedure is clearly outlined, the equipment for the test is not a standard item, which results in expensive individuality of design and in nonreproducibility of measurements.

The authors wished to obtain a simple and inexpensive apparatus for use with Methods F 219, to adapt it to the Instron tensile testing machine.

ASTM Straightness Test

Methods F 219 say, in part:

"This method is recommended for very fine wires which are produced to be as straight as possible. The apparatus is shown in Fig. 1. A sufficient length of wire shall be suspended from a fixed jaw so that the lower end is 20 in. below the fixed jaw. The specimen shall hang freely and under its own weight only. At a point 10.0 in. below the fixed jaw a movable jaw shall be fastened to the wire, making certain that no straightening or recurling of the wire is permitted in the 10.0-in. gage length. By means of a screw the movable jaw shall be lowered until the wire within the gage length is straightened. Care must be taken that the wire shall not be stretched beyond the point necessary to just remove the curl. Straightness shall be expressed as the lengthening of the original gage length in per cent."

Instron Attachment

One of the major problems, to record precisely the extent of the movement of the movable jaw, is easily overcome by making use of the movable crosshead and indicating dials of the Instron. We designed and constructed a device (Fig. 2) similar to a ring stand, with a heavy base machined to fit the top of the crosshead. The base supports a vertical rod, from which extend two adjustable horizontal arms. A clamp on the top arm becomes the movable jaw described in Methods F 219. The lower arm marks the point 20 in. below the fixed jaw, which is the upper jaw of the Instron.

[1] "Methods of Testing Fine Round and Flat Wire for Electronic Devices" (F 219-50), 1958 Book of ASTM Standards, Part 2, p. 826.

Procedure for Using the Attachment

Preparatory Steps

1. Insert the B cell of the Instron and attach the proper size upper jaw.
2. Place the straightness attachment on the crosshead and align the clamp directly below the upper jaw.

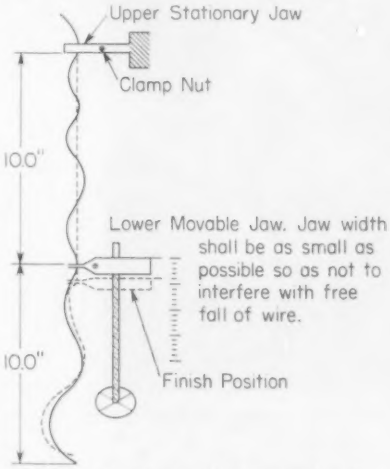
Upper Stationary Jaw
Clamp Nut
10.0"
Lower Movable Jaw. Jaw width shall be as small as possible so as not to interfere with free fall of wire.
10.0"
Finish Position

Fig. 1.—Straightness test apparatus for fine wire.

3. Adjust the crosshead height and set the crosshead controls for a 10-in. gage length between the Instron jaw and the top of the clamp. The lower arm automatically marks a position 20 in. below the fixed jaw.
4. Zero, calibrate, and balance the Instron cell, leaving the load-selector switch on the lowest position.
5. If the Instron model is equipped with a load-cycling mechanism adjust the high-load microswitch so that it will automatically stop the crosshead the instant the recorder pen begins to register a load.

Fig. 2.—Instron testing machine with attachment in place.

Testing Procedure

1. Fasten one end of a wire specimen in the upper jaw being careful not to bend or in any way alter the straightness of the wire.
2. Cut off the excess of the freely hanging specimen so that its level coincides with the marker arm.
3. Secure the wire in the movable jaw being careful not to apply any force to straighten or recurl the wire.
4. With the pen switch closed, start the crosshead downward at the rate of 0.1 in. per min.
5. When the gage length of wire is straightened, the recording pen will begin to register a load, which, on automatic control, will stop the crosshead motion. (If the machine is being operated manually, the operator will have to stop the crosshead motion the instant a load is registered on the recorder chart.)
6. The distance of crosshead travel required to straighten the wire can be read directly from the Instron dials and then converted to a percentage of the original gage length.

Applications

The authors have successfully measured the straightness of wire as fine as 0.5 mil in diameter. Shielding of the attachment is recommended when testing such fine wires in order to protect the wire from air currents. If this is not done it will be difficult to obtain satisfactory measurements.

The test can be used to measure straightness as a direct means of comparing various wires, or it can be used as a "go-no go" test for quality control. In the latter case, the crosshead controls are set to stop the crosshead motion at some distance which corresponds to a predetermined straightness value. Any wire for which a load was not registered would have a straightness value greater than the selected value and would therefore be considered unsuitable for use.

Acknowledgment:

The authors wish to thank Mr. John H. Miller of the Physical Testing Laboratory for the photographs used in this article.

RUSSELL C. NELSON and RUSSELL H. RHODES, Sylvania Electric Products Inc., Towanda, Pa.

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More "Meat" in Insulation Sales Literature Urged

AN ASTM team of six experts speaking at the second Conference on Application of Electrical Insulation in Washington in December urged that more supporting information on properties of insulation be included in sales literature. This will give real meaning to the property values reported and will help designers to select materials to fit the application. The purpose of this ASTM-sponsored session at the Insulation Conference was to promote a broader understanding of dielectric strength—what it means, how it is measured, and how results should be interpreted.

The papers were arranged to cover four phases of the subject with N. W. Edgerton of Johns-Manville Corp. speaking on dielectric-strength test equipment; Kenneth Wechsler of Westinghouse Electric Corp. on conditioning for dielectric strength tests; H. S. Endicott of General Electric Co., on procedures for measurement of dielectric strength; and C. L. Craig of Sperry Gyroscope Co. on interpretation of dielectric-strength test results.

Session Chairman was H. K. Graves, Material Laboratory, New York Naval Shipyard and chairman of ASTM Committee D-9 on Electrical Insulating Materials. Co-chairman was J. S. Hurley of General Electric Co. Attendance was about 300.

Stockholm Host City for Sixth IABSE Congress

THE SIXTH Congress of the International Association for Bridge and Structural Engineering will be held in Stockholm, Sweden, June 27 to July 1, 1960. The Congress, in which only members of the Association may take part, will include six "working sessions" on topics in design of metal and concrete structures. Visits to building sites in the Stockhom area are also scheduled. Further information is available from: Secretariat of the IABSE, Swiss Federal Institute of Technology, Zurich, Switzerland.

Paint Group Changes Its Name

THE FEDERATION of Paint and Varnish Production Clubs has changed its name to "Federation of Societies for Paint Technology." The change was unanimously approved at the federation's council meeting, Oct. 21, 1959, and became effective Jan. 1, 1960. The production of protective and decorative coatings has progressed from an art to a science, the federation says, and the purpose of the name change is to reflect that change.

Membership of the 37-year-old federation includes chemists, chemical engineers, technologists, and supervisory production personnel engaged in evaluating raw materials and in producing paints, varnishes, lacquers, and related products in the United States, Canada, and England. ASTM works closely with the federation on related problems through a joint committee established in 1944, on which ASTM is represented by members of Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

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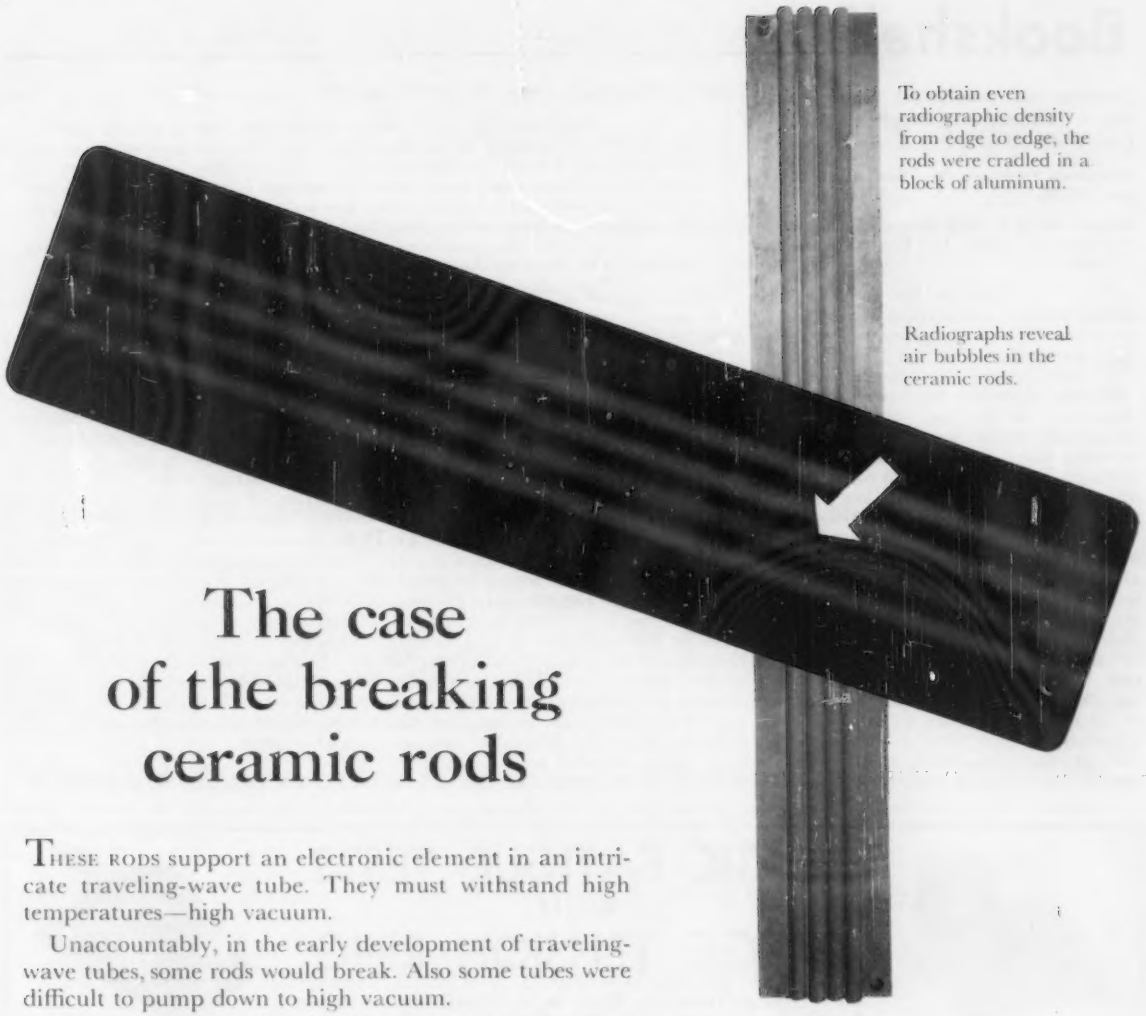

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Treatise on Analytical Chemistry Part I: Theory and Practice, Vol. 1
I. M. Kolthoff and P. J. Elving;

Interscience Publishers, New York, N. Y.; 809 pp.; $17.50.

Reviewed by W. A. Kirklin, Manager, Analytical Div., Hercules Powder Co. Research Center, Wilmington, Del.

Books reviewed here are furnished by publishers knowing of the broad interests of ASTM. Occasionally reviews are prepared by ASTM Staff members, but in most cases, the books are reviewed by Society members or other individuals who are well informed on the subject at hand. Members who wish to be considered for reviewing books are invited to send in their names and the subjects in which they are interested. Due to customs and mailing considerations, requests from the United States only can be considered.

Copies of these books are not available through ASTM; all inquiries concerning them should be addressed to the publisher.

THIS IS the first of a comprehensive many-volume work on modern analytical chemistry. The editors and authors (for they are both) have undertaken a monumental task—analytical chemistry has expanded tremendously in the past several years. Numerous books have been written covering many specific areas, but few attempts have been made to collect the different theories and practices in a form convenient for use as a whole.

The editors have been aided by 15 outstanding authors in the preparation of this volume. Section A on Objectives, Functions, and Limitations contains four chapters covering the methods of analytical chemistry, errors in analysis, evaluation and interpretation of data, and the principles of sampling. Section B on Applications of Chemical Principles to Analytical Chemistry begins with a chapter on elements and compounds. This chapter provides a good discussion of the modern theories of atomic structure, properties, and molecular bonding, which form the basis for many analytical procedures. It is followed by 14 additional chapters on atomic weights, chemical equilibria and thermodynamics of reactions, concepts of pH and acids and bases, complexation and oxidation-reduction reactions, solubility, precipitates, and equilibria in precipitation reactions. The chapter on graphic presentation of equilibrium data directs attention to the advantages of graphs for attacking complicated systems. Each chapter is preceded by a detailed table of contents and is documented by extensive references to more comprehensive publications. Also, many tables of data on properties of solutions and analytical systems are included in the different chapters. Several of the authors have indicated areas for further research, for example: exact studies of equilibria in Lewis acid-base systems, complexation reactions, and specific studies in precipitation reactions and their equilibria.

This presentation of chemical principles points up their relationship in analytical chemistry and the necessity for considering them collectively for solution of many analytical problems. This volume will be very useful not only to the student of analytical chemistry, but also to practicing analytical chemists and others. When supplemented by the additional volumes of Part I (more than 100 additional chapters are planned), it will indeed be a valuable work.

The book is well printed (two misspellings were observed), very readable, and of convenient size. The additional volumes of this treatise will be awaited with interest.

(*Continued on p. 65*)

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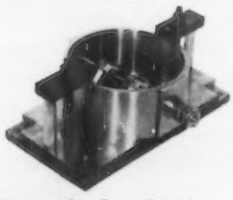

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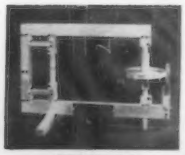
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68 pages, 8½ by 11 in., paper cover
Regular Prices: $3.75; Members, $2.80

This volume includes data for tensile and yield strength, elongation and reduction of area, stresses for creep rates of 0.0001 and 0.00001 per cent per hr and rupture strengths for 100, 1000, 10,000 and 100,000 hr.

The steels covered are: killed carbon steels (0.12 to 0.17 C), (0.18 to 0.24 C), and (0.27 to 0.58 C); ASTM A 201 Grade B plate steel (0.24 C max); ASTM A 106 Grade B pipe steel (0.30 C max); aluminum killed steel, open steel (rimmed or capped), and miscellaneous carbon steels (limited data available).

The properties are given in graphical form and supplemented by copies of original data sheets from those contributing the data.

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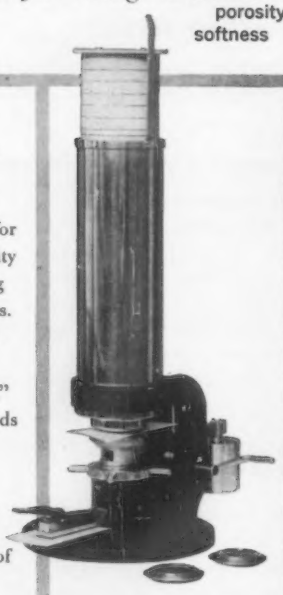

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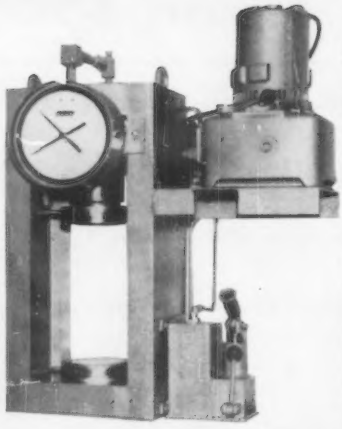

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(*Continued from p. 62*)

Guide to the Space Age

C. W. and Hazel C. Besserer; Prentice-Hall, Inc., 70 Fifth Ave., New York 11, N. Y. (1959); 320 pp, $7.95.

THIS BOOK contains more than 5000 definitions, alphabetized and cross-referenced. Figures and tables, where useful, clarify descriptions or concepts. Slang expressions like "crossing the trough," "cookie cutter," "panic button," and "boot strap"[1] are defined. Also covered are abbreviations such as: SSM, PFRT, and DEW.[2] The authors describe many space vehicles and cover terms which have crept into the space vocabulary from astronomy, meteorology, and related sciences.

[1] In order: Process in an earth-to-moon voyage of passing from the influence of terrestrial gravity to the region of space where lunar gravity predominates. A sharp-edged intake for any air-breathing engine. A control button or switch for use in some emergency. In liquid rocket engine usage, a regenerative process used for starting. A portion of the turbopump output is fed back to the gas generator which causes an increase in energy available for driving the turbopump; which, in turn, delivers a greater quantity of propellants to the gas generator. The cycle terminates when rated system performance has been attained.

[2] In order: Surface-to-Surface Missile. PreFlight Rating Test. Distant Early Warning.

ACI Standards 1959

American Concrete Inst., P. O. Box 4754, Redford Station, Detroit 19, Mich.; 382 pp; $5.

Reviewed by L. C. Gilbert, ASTM Staff.

THE LATEST issue of the ACI Standards is now available in a compact publication. This brings together under one cover all of the standards approved by the American Concrete Inst. to date.

Two new standards appear in the compilation for the first time, both being of considerable interest to the engineer and concrete specialist.

A Recommended Practice for Hot Weather Concreting (ACI 605-59) provides information useful in minimizing detrimental effects of hot weather on concrete temperature—methods of production and delivery; and care in placement, protection, and curing.

A Recommended Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 613A-59) is actually a supplement to the ACI Recommended Practice for Selecting Proportions for Concrete (ACI 613-54). The growing use of lightweight aggregates has led to this report on a procedure for proportioning structural grade concrete containing lightweight aggregate. An innovation in proportioning procedure,

(*Continued on p. 68*)

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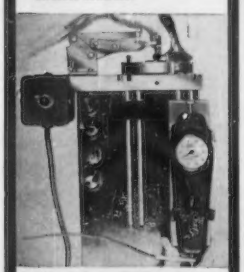
On production line, determining carbon brush pressure.

Hunter Mechanical Force Gages are precision, direct reading instruments designed for use in inspection departments and laboratories, on production lines, or in the field to measure tension and compression loads. Accurate to within 1% of full scale, they can be hand-held or used in fixtures depending upon use.

The indicator can be made to hold maximum reading until released (no "follower" hand used) or the indicator can be made free moving. Gages are available as noted under illustrations above. Each unit is supplied with six attachments—extension rod, flat knob, notch, hook, cone, and chisel edge—in a compact wood instrument box. Prices are low enough to permit any company to buy one for evaluation. Quantity prices are also offered.

Hunter Bulletin 750c contains full details. Copies are available immediately on request.

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- **FOR DYNAMIC TESTING: AMSLER PULSATOR,** used with AMSLER jacks, produces true sinusoidally alternating loads. Pre-load or lower limit is automatically kept constant; upper limit is set by adjusting stroke of the piston. Built-in safety feature stops pulsator at fracture of specimen or change in predetermined load.

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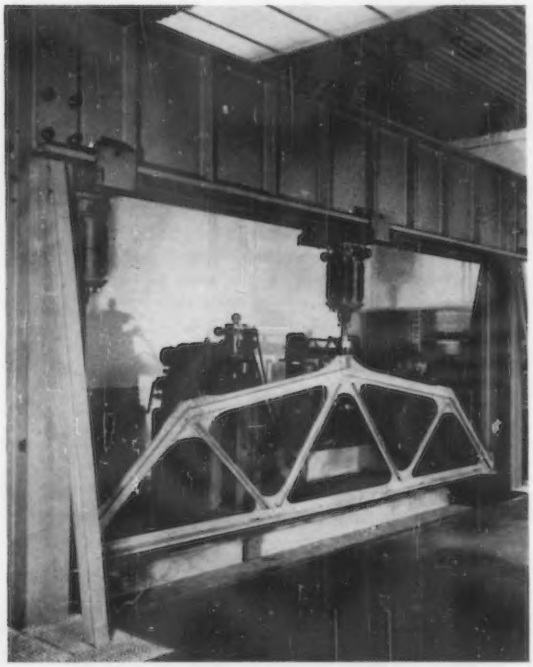
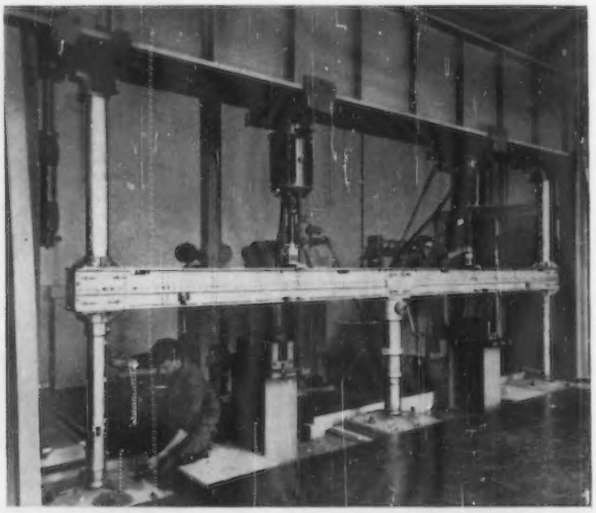
- **AMSLER ARTICULATED STEEL PIPES** with self-sealing swivel joints are available in various lengths to connect the several units.





For detailed descriptive literature, write or phone any of the three Carl Hirschmann Company offices

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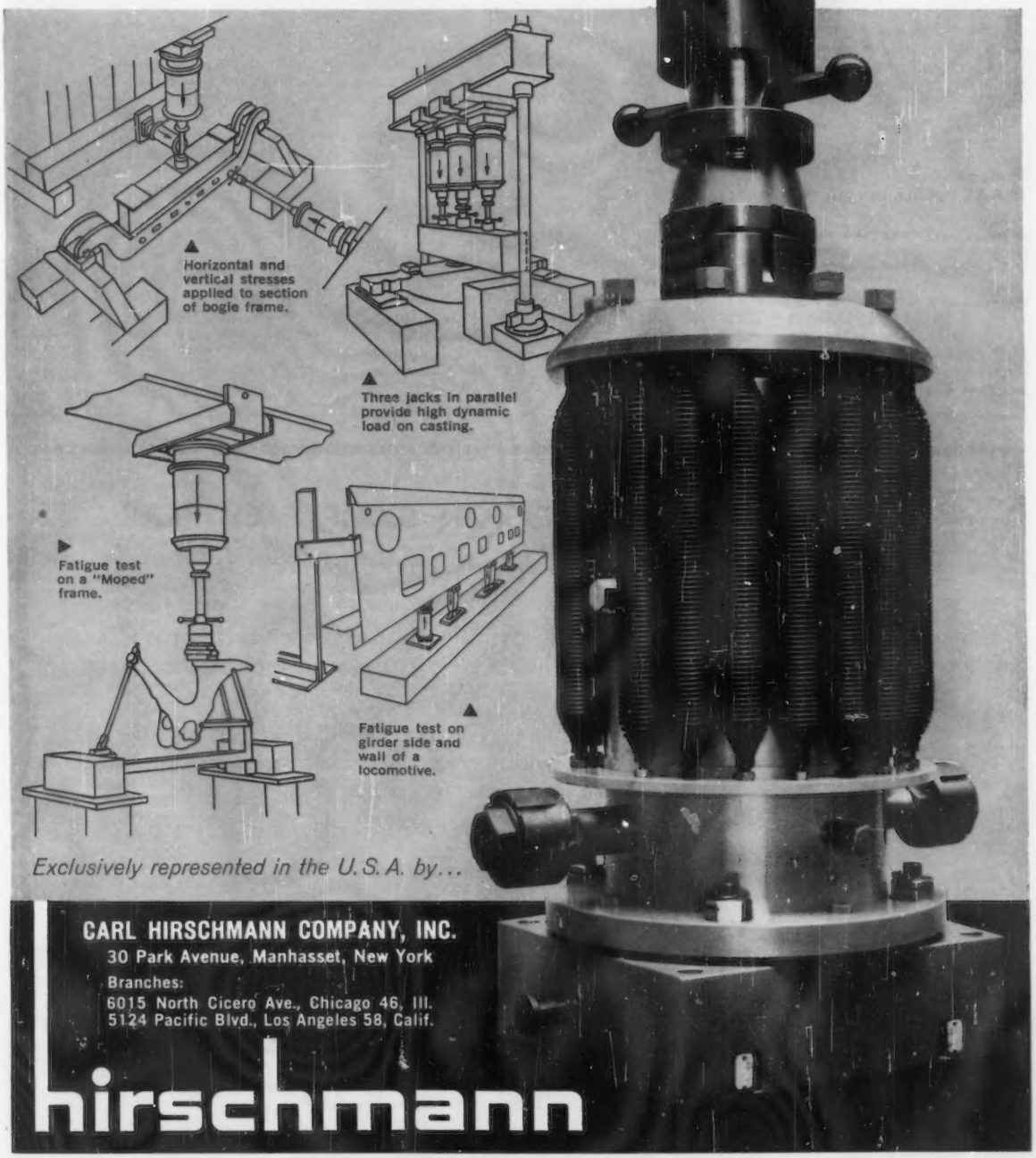
▲ Horizontal and vertical stresses applied to section of bogie frame.
▲ Three jacks in parallel provide high dynamic load on casting.
▶ Fatigue test on a "Moped" frame.
▲ Fatigue test on girder side and wall of a locomotive.

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(*Continued from p. 65*)

the use of a specific gravity factor, is illustrated by examples in this compilation.

The 16 standards in this publication now include: ten recommended practices covering a range of application from design of reinforced concrete to the construction of concrete farm silos; two specifications for design and construction of reinforced chimneys and concrete pavements and bases; a test procedure to determine relative bond value of reinforcing bars; building code requirements for reinforced concrete; a manual of standard practice for detailing reinforced-concrete structures; and minimum standard requirements for precast concrete floor and roof units.

Symposium on Basic Research (AAAS Publication No. 56)

Edited by Dael Wolfle; American Association for the Advancement of Science, Washington, D. C.; 308 pp.

Reviewed by R. J. Painter, ASTM Staff.

THIS SYMPOSIUM, held in May, 1959, in New York City, was sponsored by The National Academy of Sciences, The American Association for the Advancement of Science, and The Alfred P. Sloan Foundation.

Presumably, the underlying cause for the symposium is the fact that our reservoir of basic knowledge has not been replenished in the past few years at nearly the volume it should be if we are to maintain our position as a leading industrial nation. In his preface, Dr. Warren Weaver, past-president of AAAS, states the purpose of the symposium as follows:

"It is the purpose of this symposium to set forth and examine with candor the facts concerning the support of basic research in our country; to inquire realistically what are the blocks which prevent our doing what we all say we believe is important; to make concrete suggestions as to ways in which the situation can be improved; and in general to proclaim the fundamental faith which we have in the importance of free and imaginative basic research, and to do this with such competence and vigor as will have a national impact."

Many of the country's leading scientists, teachers, and executives participated. Contributions bear such names as Oppenheimer, Waterman, Baker, DuBridge, Killian, Greenawalt, Astin, and Robert Wilson. These, together with a significant contribution by the President of the United States, make up the symposium, which has been skillfully edited by AAAS Secretary Dael Wolfle, who leans heavily on summaries furnished by rapporteurs in each of the sessions.

It is noted that the one completely indispensable element in basic research is the scientist with an idea. How he can be helped by equipment and services and where this is to come from are extensively discussed. The symposium notes, for example, that universities must always be expected to perform the largest share of basic research, and in order to expand activities they must have larger amounts of unrestricted money. If the universities have enough unrestricted money to carry out effective programs, we can expect that they will maintain a fair balance between teaching and research. The place of government, industry, and private foundations is also discussed.

This publication should be "must" reading for anyone who has responsibility in the field of research of any kind.

Dr. Allen Astin, director of the National Bureau of Standards, says "we must recognize government has a responsibility for fostering basic research, even for its nonutilitarian values." President Eisenhower speaks for a free science:

"Science, great as it is, remains always the servant and the handmaiden of freedom. And a free science will ever be one of the most effective tools through which man will eventually bring to realization his age-old aspiration for an abundant life, with peace and justice for all."

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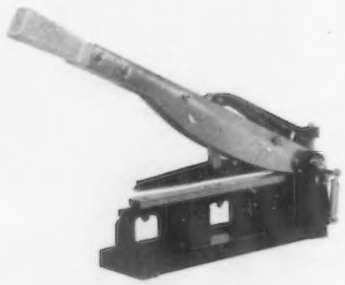

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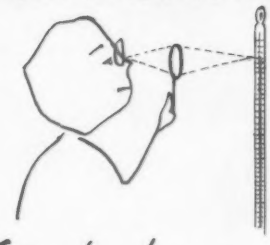

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Jacqmain, J. L., technical director, Maher Color and Chemical Co., 1700 N. Elston Ave., Chicago 22, Ill. [A]*

Marino, Robert L. Jr., assistant professor, civil engineering, Valparaiso University, Valparaiso, Ind. [A]

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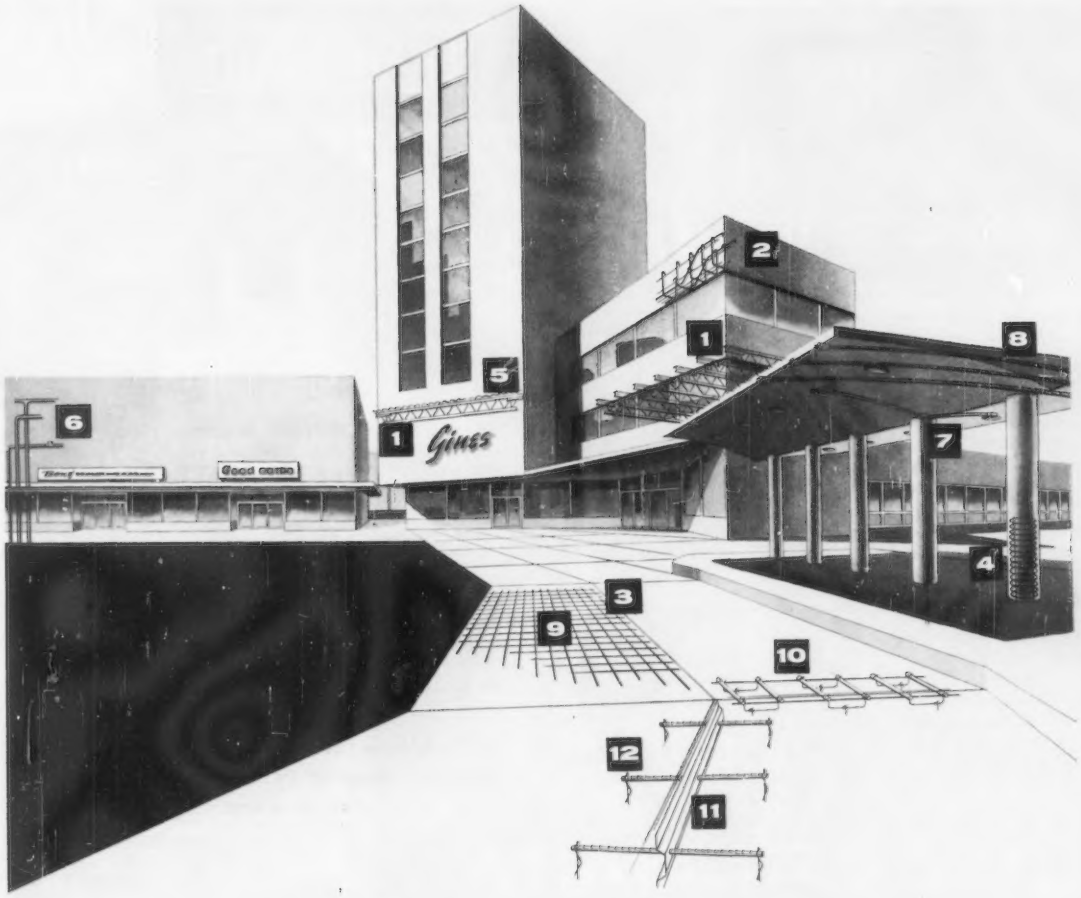
(*Continued on p. 73*)



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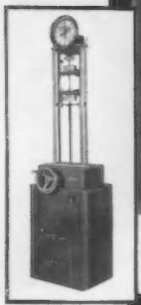

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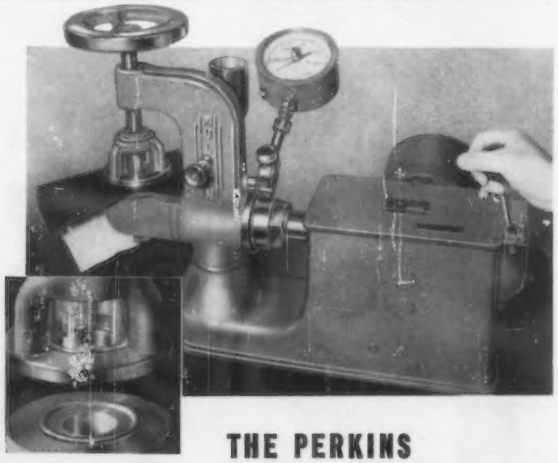

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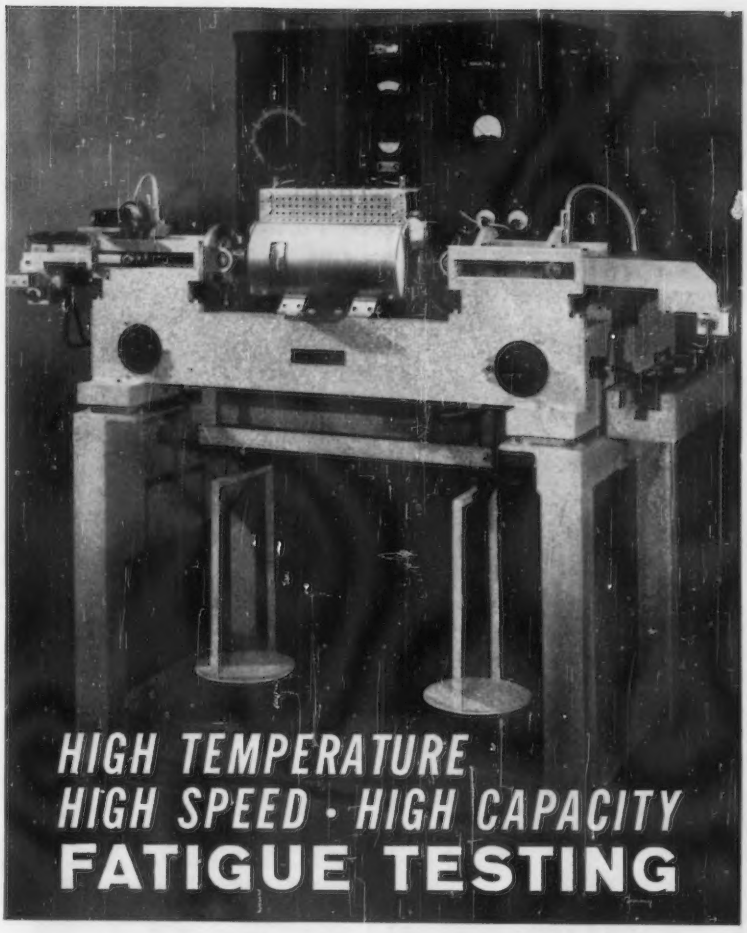

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NEW MEMBERS

(*Continued from p. 73*)

Arzano, Roberto, head, Servizio Studi and Documentazione Tessile, Rhodiatoce S. p.a., Piazza Erculea, 15, Milan, Italy.

Bailey, Gordon Lennox James, superintendent, Development and Research Department Laboratory, The Mond Nickel Co. Ltd., Wiggin St., Birmingham 16, England.

El Dib, Adel Hussein, mechanical engineer, International Inspecting Office, 19 Grupellostr, Dusseldorf, Germany. For mail: 134 Luisenstrasse, Dusseldorf, Germany. [A]

Junta Cantonal de Agua Potable de Guayaquil, Guillermo Varas P., ingeniero civil, MSPH, Casilla No. 5352, Guayaquil, Ecuador.

Kubek, Zdenek, chief engineer, Spolek pro chemiepou a hutni vyrobu, Usti nad Labem, Czechoslovakia.

Mallcott, Frederick Lamont, pressure vessel inspector, Edificio Easo, 50 Piso, F. Avda. Fsco de Miranda, Chacaito, Carcas, Venezuela.

Martin, C. W. G., Oil Products Development Div., Shell International Petroleum Co., Ltd., St. Helens Court, Great St. Helens London, E.C. 3, England. For mail: 16 Finsbury Circus, London, E.C. 2, England.

Morris, Bruce D. W., chemist, B.D.M. Laboratory, 12 Wilkinson St., Brunswick N.10, Melbourne, Victoria, Australia. [A]

Papaioannou, Constantinos, P., professor, National Technical University of Athens, 22 Icaovidou St., Athens 9, Greece.

Ramirez, Gerardo E., supervising civil engineer, Civil Aeronautics Administration, Republic of the Philippines, 29 Matutum St., San Franciso del Monte, Philippines.

Stokoe, Edward, partner, Depauw, Stokoe & Lenaerts S.A., 21-23 Longue rue Neuve, Antwerp, Belgium.

OTS Research Reports

THESE REPORTS, recently made available to the public, can be obtained from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. Order by number.

Lubricating Oils and Greases in the Soviet Union, PB 151294, $2.50.
Thermal Conductivity of Lubricating Oils and Hydraulic Fluids, PB 151780, $1.50.
Thermodynamic Properties of Helium at Low Temperatures and High Pressures, PB 151367, $1.25.
Starting of Diesel Engines at Low Temperatures, PB 151676, $1.25.
The Vapor Pressures of Some Hydrocarbons in the Liquid and Solid State at Low Temperatures, PB 151363, 75 cents.
Solid State Chemistry: Final Report on the Activity during the Period of this Contract, PB 151440, $1.
Current Status of Cemented Carbide Technology, PB 151302, $1.
AEC Research Reports, Price List No. 32, free.
Ceramics and Refractories, CTR-373, 10 cents.
Apparatus for Measurement of the Magnetic Threshold Curves for Superconductors, PB 151877, 50 cents.
Theoretical and Experimental Studies of the Stresses and Strains Around Cutouts in Loaded, Unevenly Heated Plates, PB 151867, $3.
Effect of Changing Cyclic Modulus on Bending Fatigue Strength: Part 2, PB 151853, $1.
Investigation of Solidification of High-Strength Steel Castings Under Simulated Production Conditions, PB 151753, $1.50
A New Approach to Analyzing the Phases of Alnico, PB 151882, $1.25.
Research of the Recrystallization of Aluminum Single Crystals, PB 151862, $2.25.
The Aluminum-Silicon Eutectic, PB 151735, 50 cents.
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Cermets, 1940–59, CTR-319, 10 cents.
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Packing and Carloading, PB 15325, $5.
Effect of Combined Fire and Water on Silicone Insulated Cables Final Report, PB 151751, 50 cents.
Properties of Polyethylene and Related Polymers, PB 151584, $1.50
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Development of Inorganic Polymer Systems, PB 131935, $1.75.
Development of Ultra-High Strength, Temper-Resistant Steels Designed for Improvement of Fatigue Properties Through Relief of Residual Stress, PB 151971, $1.
Mechanical Properties of 17-7 PH and PH 15-7 Mo Stainless Steel, PB 151703, $1.
Crack Propagation Tests of High-Strength Sheet Materials, PB 151770, 50 cents.
Physical Metallurgy of Precipitation-Hardenable Stainless Steels, PB 151067, $2.
The All-Beta Titanium Alloy (Ti-13 V-11 Cr-3Al), PB 151066, $3.
Rapid Separation and Gravimetric Determination of Aluminum in Ferrous Metals, PB 161003, 50 cents.
Simple Laboratory Bulge Tests for Sheet-Metal Fracture-Transition Studies and for Weldment-Performance Evaluation, PB 151771, 50 cents.
A Remotely Operated Charpy Test Machine for Radioactive Specimens, PB 151636, 50 cents.
Effect of Changing Cyclic Modulus on Bending Fatigue Strength, PB 151897, $1.
Damping Energy Dissipation at Support Interfaces of Square Plates, PB 151972, 75 cents.
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Thermistor Infrared Detectors, Part 1—Properties and Developments, PB 151767, $2.75.
Infrared Atomic Spectroscopy, Based on Use of Photoconductive Detectors, PB 151953, $1.25.
A New Instrument for the Determination of Molecular Weight by Differential Vapor Pressure, PB 151832, $1.

Papers to Appear in Future Issues of the ASTM Bulletin

A Study of Rheological Testing of Elastomers at Low Temperatures, Part II—L. Boor, Military Clothing and Textile Supply Agency, U. S. Army; Max Hanok, New York Naval Shipyard; F. S. Conant, Firestone Tire and Rubber Co.; and W. E. Scoville, Jr., Boston Woven Hose and Rubber Co.

Measurement of the Brittleness Temperature of Polyethylene—A. M. Birks and R. Rudin, Canadian Industries, Ltd.

Measurement of Environmental Stress Cracking of Polyethylene—A. Rudin and A. M. Birks, Canadian Industries, Ltd.

Design Criteria for 6Al-4V Titanium Alloy at Room and Elevated Temperatures—J. K. Childs and M. M. Lemcoe, Southwest Research Inst.

The Gravimetric Determination of Strontium Oxide in Portland Cement—C. L. Ford, Portland Cement Assn.

A Vicat-Type Penetration Tester for Evaluating Hardness and Elastic Recovery in Polymeric Materials—K. W. Gardiner, T F Jordan, and F. W. Adams, Continental Can Co., Inc.

Movement of Sodium with Water in Neat Portland Cement—R. C. Hall *and J. M. Rhodes*, Kansas State Univ.

An Improved Method for the Determination of the Normal Consistency of Plasters—R. A. Kuntze, Ontario Research Foundation

The Use of 2,2,4,4,6,8,8-Heptamethylnonane as a Primary Diesel Reference Fuel—T. W. Mears, R. M. David, and F. L. Howard, National Bureau of Standards.

Comparison of Four Particle Size Distribution Techniques—A. I. Michaels, T. L. Weaver, and R. C. Nelson, Sylvania Electric Products, Inc.

A Burst Test of High-Strength Fabrics—K. F. Plitt and L. A. Dunlap, National Bureau of Standards.

Tests for Potential and Past Moisture Expansion of Ceramic Building Units—E. H. Waters, J. S. Hosking, and H. V. Hueber, Commonwealth Scientific and Industrial Research Organization of Australia.

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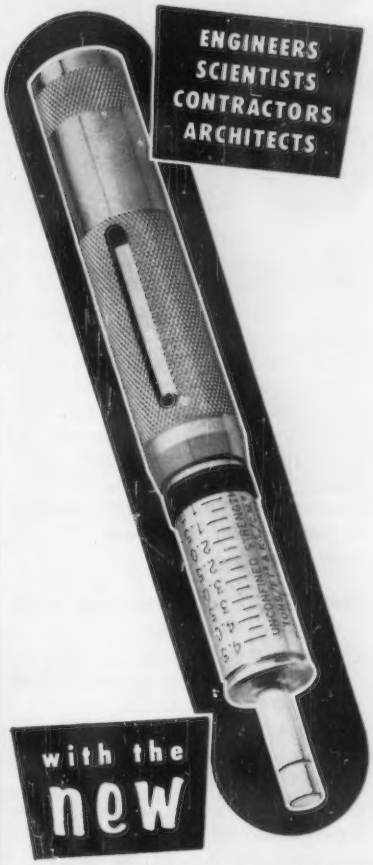

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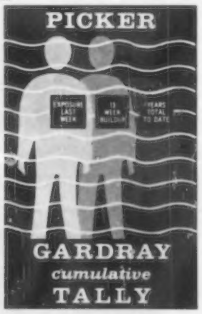

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NEWS OF MEMBERS...

News items concerning the activities of our members will be welcomed for inclusion in this column.

The American Chemical Society's divisions elected new officers and several ASTM members were among those elected chairman of a division: **A. O. Battista,** head, Analytical Laboratories, Research and Development Div., American Viscose Corp., Marcus Hook, Pa., chairman, Division of Cellulose Chemistry; **Stephen Brunauer,** manager, Basic Research Section, Portland Cement Assn., chairman, Division of Colloid Chemistry; **Richard A. Glenn,** supervising chemist, Bituminous Coal Research, Pittsburgh, Pa., chairman, Division of Gas and Fuel Chemistry; **Wheeler G. Lovell,** director, Automotive Products Development, Ethyl Corp., Detroit, Mich., chairman, Division of Petroleum Chemistry. New advisors to ACS Applied Publications include ASTM members **Foster D. Snell,** president, Foster D. Snell, Inc., New York, N. Y., and **Bourdon F. Scribner,** chief, Spectrochemical Section, National Bureau of Standards, Washington, D. C

Herbert Bandes has been named director of research and development, Western Div., Arthur D. Little, Inc., San Francisco, Calif.

Rosemond K. Bell, associate chemist, National Bureau of Standards, Washington, D. C., has been awarded the Silver Medal for Meritorious Service of the U. S. Dept. of Commerce for superior performance in the precise chemical analysis of metals and alloys.

Frank M. Biffen, research specialist, Johns-Manville Research Center, Manville, N. J., is now retired. Mr. Biffen joined the Society in 1945 and over the years has been active in the work of Committees D-1 on Paint, Varnish, Lacquer and Related Products, and C-1 on Cement.

Seymour L. Blum has been appointed manager, High Temperature Materials Dept., Research Div., Raytheon Co., Waltham, Mass. Dr. Blum had been head of the Ceramics Section, Solid State Physics Group.

Malcolm A. Buell retired Dec. 1, 1959, from the Bridgeport Brass Co., Bridgeport, Conn. Mr. Buell represented his company on Committee B-5 on Copper and Copper Alloys, Cast and Wrought.

Orval W. Daniels is now a partner in the Engineering Testing Co., Wichita, Kans. Formerly he was manager, Tulsa Testing Laboratory, Wichita, Kans.

Earl H. Davidson, a member of the Society since 1928, retired Dec. 31, 1959, from his position as manager, Structural, Plate, and High Strength Steel Metallurgy, United States Steel Corp., Pittsburgh, Pa. For many years, Mr. Davidson was an active member of Committee A-1 on Steel in the area of structural steel and plates for boilers and pressure vessels. He and others of his era were responsible for developing the wide recognition given to ASTM specifications for these products in industry today. Mr. Davidson is now residing at 1000 S. E. Fourth St., Fort Lauderdale, Fla.

Joseph V. Emmons, metallurgical and research consultant, The Cleveland Twist Drill Co., Cleveland, Ohio, retired Dec. 31, 1959. Mr. Emmons represented The Cleveland Twist Drill Co. in Society membership and on Committees A-1 on Steel, A-8 on Magnetic Analysis, and E-4 on Metallography. He also served on the Cleveland District Council from its organization in 1931 to 1937 and again from 1943 to 1954. Mr. Emmons will continue his contact with the Society through individual membership.

Robert C. Ferris leaves Purex Corp., South Gate, Calif., where he was director of research, to become president, Chem Lab Products, Inc., Norwalk, Calif.

Eugene W. Friedrich is associated with Turner Construction Co., Glendale, Lombard, Ill., as an engineer. He had been aeronautical research engineer, National Aeronautics and Space Administration, Langley Field, Va.

John Geyer, manager of product development, Metalworking Chemicals Div., Amchem Products, Ambler, Pa., has been promoted to technical assistant to the president.

Allen Gutekunst, formerly a finishing supervisor, Smith-Corona-Marchant, Inc., Syracuse, N. Y., is now associated with General Electric Co., Waynesboro, Va., as manufacturing engineer.

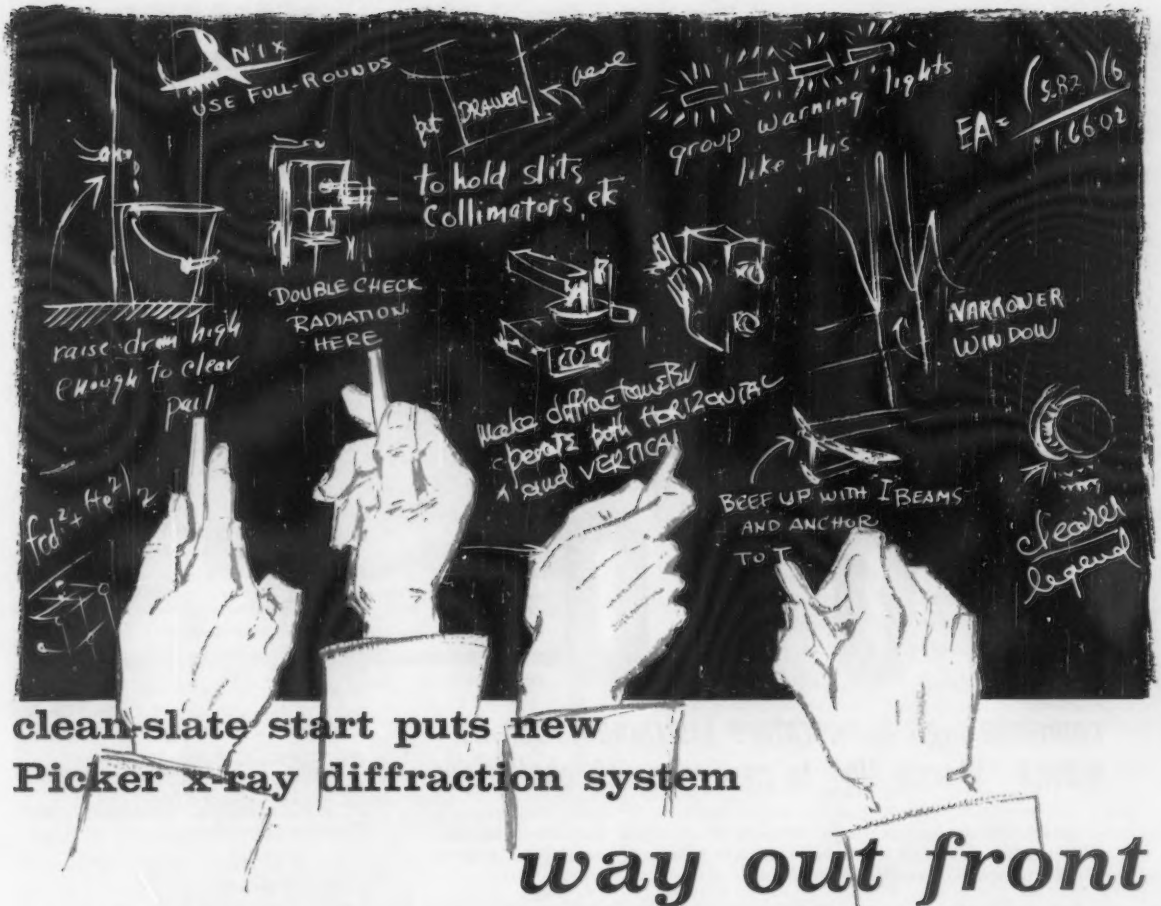
William A. Hamor, senior director of research, Mellon Institute of Industrial Research, Pittsburgh, Pa., retired Dec. 31, 1959, after 45 years of service. Dr. Hamor joined the Society in 1922.

Philip S. Hessinger has been named manager of research, National Beryllia Corp., North Bergen, N. J. He had been acting director of research and development, Mycalex Corp. of America, Caldwell, N. J.

Frank P. Iapalucci was made plant manager, Lake Erie Machinery Corp., Buffalo, N. Y., subsidiary of Wheelabrator Corp. Formerly he was with Baldwin-Lima-Hamilton Corp., Philadelphia, Pa.

Augustus B. Kinzel, vice-president, research, Union Carbide Corp., New York, N. Y., received the James Douglas Gold Medal. This distinction was conferred upon Dr. Kinzel by the American Institute of Mining, Metallurgical, and Petroleum Engineers "for outstanding contributions

(*Continued on p. 78*)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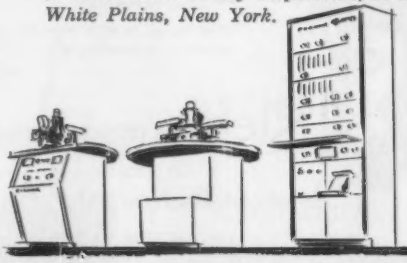

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(*Continued from p. 76*)

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John C. King has been named product development engineer, Master Builders Co., Division of America-Marietta Co., Cleveland, Ohio. Until recently he was chief engineer, Intrusion Prepakt, Inc., Cleveland, Ohio.

Harry Larson is director, Engineering and Public Works, Village of Lombard, Ill. Col. Larson is retired from the United States Army and is a consulting engineer.

Alan V. Levy is now manager, Hughes Tool Co., Aircraft Div., Los Angeles, Calif. He had been supervisor Marquardt Aircraft Co., Van Nuys, Calif.

J. B. McMorran, who had been superintendent of public works, has been appointed head of the New York State Department of Public Works, Albany, N. Y.

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R. William Parsons, previously with the Western Contracting Corp., Yankton, S. Dak., is junior engineer, City of Sioux City, Iowa.

M. W. Richardson, Jr., is a sales engineer, Farrel-Birmingham Co., Inc. Akron, Ohio. He served in the same capacity for C. A. Litzler Co., Inc., Cleveland, Ohio.

J. B. Schaub, a member of the Society since 1956, retired Dec. 31, 1959, after 42 years of service in various capacities with the Illinois Central Railroad, Chicago, Ill.

Romer Shawhan, director, Marble Institute of America, Inc., Mt. Vernon, N. Y., retired Jan. 1, 1960. Mr. Shawhan joined ASTM in 1956 and since that time was a member of Committee C-18 on Natural Building Stones.

Hal Shidemantle was made manager, Engineer Materials Laboratory of Mack Trucks Research Dept., Mack Trucks, Inc., Plainfield, N. J. Previously he was affiliated with Jack & Heintz, Cleveland, Ohio, as manager, materials and processes, Engineering Dept.

B. M. Smalley, executive vice-president, Joslyn Mfg. and Supply Co., Chicago, Ill., retired Jan. 1, 1960. Mr. Smalley represented his company's sustaining membership in the Society and participated in the activities of Committee A-5 on Corrosion of Iron and Steel.

Charles T. Smith, former manager of the Danbury Metal Co., Danbury, Conn., is now president, Electronics Metal Finishing, Brookfield, Conn.

Robert L. Smith currently is manager, national accounts and technical service, Philip Carey Mfg. Co., Bellwood, Ill. Formerly he was with Owens-Corning Fiberglas Corp., Chicago, Ill., in the National Account Technical Service.

Fritz M. K. Werdouschegg is now project leader, Hudson Pulp and Paper Corp. Palatka, Fla. He had been a chemist at Case Brothers, Inc., East Hartford, Conn.

Reginald V. Williams, president, Williams Gold Refining Co., Buffalo, N. Y., received the 1959 Frank J. Tone Medal Award. It is given annually by the Niagara Frontier Section of the American Institute of Mining, Metallurgical, and Petroleum Engineers.

DEATHS . . .

W. Raymond Kerr, chief chemist, Armstrong Cork Co., Beaver Falls, Pa. (December 3, 1959). For almost 30 years, Mr. Kerr was an active member of Committee C-8 on Refractories, having served as secretary from 1948 to 1956.

Edward Schramm, director of research, Syracuse China Corp., Syracuse, N. Y. (August 7, 1959). Mr. Schramm was a member of the Society since 1948 and was an active member of Committee C-21 on Ceramic Whitewares and Related Products.

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9235-S. Ditto, without stirring bars 36.50

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CIRCLE 506 ON READER SERVICE CARD

NEWS NOTES ON
Laboratory Supplies and Testing Equipment

Note. This information is based on literature and statements from apparatus manufacturers and laboratory supply houses. The Society is not responsible for statements advanced in this publication.

Laboratory Items

Sodium Dispersions—Now available are two chemicals, sodium-naphthalene dispersion and 50 per cent sodium in mineral oil.
Acton Laboratories 3296

Accelerometer Calibrator—The Model 4290 calibration exciter is designed to vibrate accelerometers or other small vibration pickups at a constant test level over the frequency range from 50 to 30,000 cps.
B & K Instruments, Inc. 3297

pH Meter—New pH meter offers an extended range, utilizing large, clear, duplex scales covering 0 to 10.0 pH and 4.0 to 14.0 pH. It uses Coleman screw-base electrodes and also accepts all other modern pH electrodes.
Coleman Instruments 3298

Environmental Chambers—A complete line of environmental chambers especially designed for testing wire and insulation breakdown in accordance with military specifications is available.
Cincinnati Sub Zero Products 3299

Flush-Mounted Strain Gage—A flush-mounted pressure transducer with improved high-frequency performance is announced as a supplement to recently introduced "high performance" line of unbonded strain-gage pressure transducers. The new Type 4-327 is obtainable in pressure ranges from 0 to 100, to 0 to 5000 psi gage and absolute. Because the pressure-sensitive diaphragm is flush-mounted, it can easily measure high-frequency transient phenomena.
Consolidated Electrodynamics Corp. 3300

Magnetic Tape Recorder—The Model MR-43 tape transport is a rugged, compact assembly designed for use in the flight testing of ballistic missiles. This unit, in combination with the Type DR-24-2 electronics, provides the means for recording and delayed reproduction of two channels of RDB telemetry subcarrier signals.
Cook Research Laboratories, Div. of Cook Electric Co. 3301

Wattmeter—New electronic wattmeters designed for measurements at sustained accuracy and resolution down to 0.01 per cent of rated input have been announced. Versatile in application, the new Model 1483 wattmeter provides varied power measurements and resolution.
Daystrom, Inc. 3302

Ultrasonic Testing—A new, compact, ultrasonic inspection tank, which can be placed and operated on a desk top, may provide the answer for convenient and space-saving ultrasonic testing. The new tester, "Mault," a manual or automatic ultrasonic laboratory testing tank, which measures 26 by 30 by 26 in. is available.
Elion Ultrasonics, Inc. 3303

Oxygen Flask—A safe, convenient, and reliable electrical ignition apparatus for use with the Schoeniger oxygen flask method is announced. It is ideally suited for decomposing organic samples prior to analysis for halogens (including fluorine), sulfur, phosphorus, and various metals.
F & M Scientific Corp. 3304

Leak Detector—Leakage areas around joints in pressure lines or tanks can be instantly, safely located with Detect-A-Leak. It is a noninflammable, noncorrosive liquid (not a soap), packaged in hand containers with an applicator brush attached to the cap for quick brushing over threads, fittings, or other suspected areas.
Flamort Chemical Co. 3305

Soil Sampler—Soil sampler offers full hydraulic operation, rotary head, portability, and low cost. Ideal for obtaining undisturbed core samples.
The Giddings Machine Co. 3306

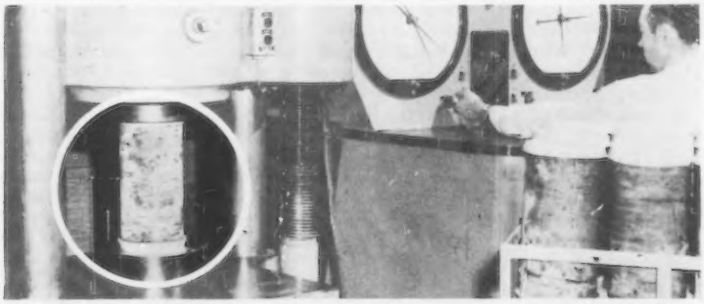
Testing Screen—Porta-Screen, a portable hand- or motor-driven aggregates testing screen, has been announced. Porta-Screen will be capable of operation free-standing on any surface, on bare ground—with spiked foot pads, or bolted to a semipermanent location. According to preliminary specifications, Porta-Screen will handle samples weighing up to approximately 25 lb, in sizes up to approximately 2 in.
Gilson Screen Co. 3307

Frequency Standard—A compact precision frequency standard, providing a stability of 5×10^{-8} parts per week and 3×10^{-8} over short intervals, is now available. The Model 100ER standard provides a wide variety of output signals.
Hewlett-Packard Co. 3308

Pyrometer—A new version of a portable indicating pyrometer intended to measure temperatures between 40 and 200 F is introduced.
Illinois Testing Laboratories, Inc. 3309

Transportation Simulator—A new Conbur (incline-impact) transportation simulator with 400-lb capacity is available. It is designed for the smaller testing laboratories; however, it is also ideal where additional equipment is needed to relieve overburdened test schedules on larger equipment.
L. A. B. Corp. 3310

(*Continued on p. 83*)



Here's a capping material that sets to 10,000 PSI in 5 minutes

- CYLCAP is more economical
- CYLCAP is easily poured
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OREC 0300 *Automatically Controlled Ozone Test Chambers*

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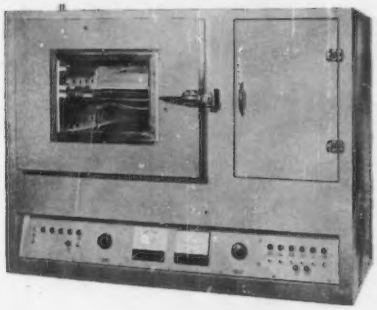
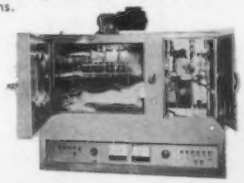


Orec 0300 Series employ an *electronic-chemical loop feed back servo system to achieve and precisely maintain chamber ozone concentrations.



Orec 0300 with Dynamic Stretching Apparatus.
* *patent pending*

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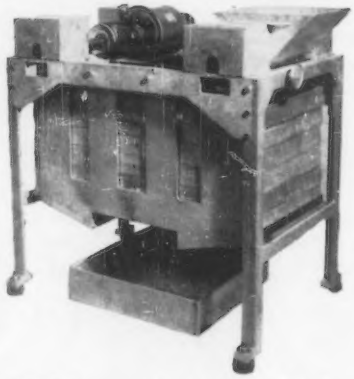
WHEELER MATERIAL GRADER



- *Designed to test large samples*
- *Capacity 50 pounds*
- *Variable speeds can be changed while machine is in motion*
- *Six screen trays—3 square feet of surface for each tray*
- *Portable—only 200 lbs.—no foundation needed*
- *Handles coarse or fine material*
- *Can be used for continuous screening—500 lbs./hour*
- *Screens changeable without removing chute*
- *Two identical cams of equal throw—synchronized with timing gears and belt—counterbalanced to eliminate vibration from base*
- *Uniform vertical circular motion removes cause of fatigue*
- *Variety of screens*

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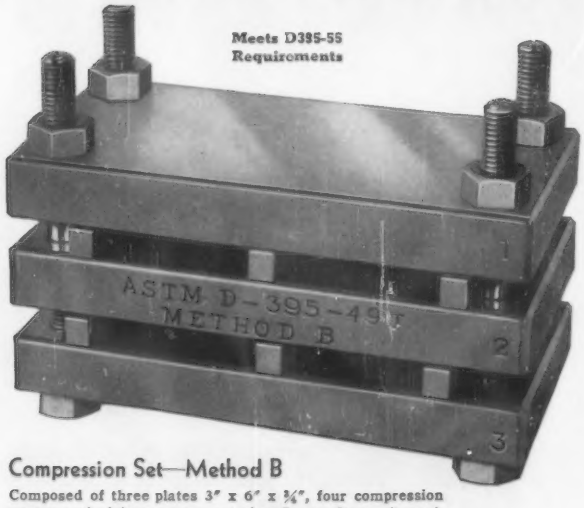
HOGGSON

TOOLS, MOLDS AND DIES

for rubber testing to ASTM standards



Compression Set—Method B

Composed of three plates 3" x 6" x ¾", four compression screws and eight nuts, one set of 12 Spacer Bars, six each 300-.350 and .375-.400. All parts chrome plated.

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The set at the left is only one of a wide variety of equipment we make for cutting and molding test samples of rubber, plastic, or other synthetic materials for determining adhesion, abrasion, flexing, compression, rebound, etc.

These molds and dies are fabricated of high grade steel and precision finished to recognized ASTM standards of practice. If you will send us your blue prints or tell us what you need, we will send full details without obligation. We also manufacture a full line of production tools for working rubber and plastics.

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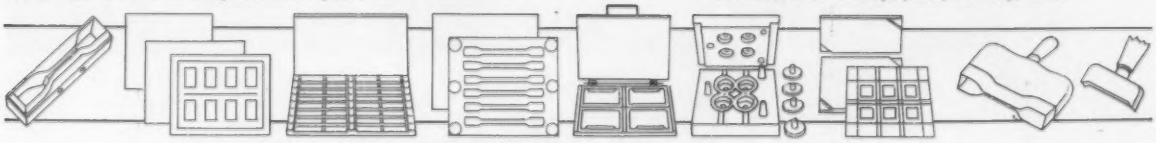
Pac. Coast: H. M. Royal, Inc., Downey, Calif.



FOR FURTHER INFORMATION CIRCLE 512 ON READER SERVICE CARD

LABORATORY ITEMS

(*Continued from p. 80*)

Sampling Device—The development of a unique new tool for taking pin samples from solid material is announced. This tool is essentially a drill with a hollow bore, which upon cutting into metal, leaves a center core or pin standing. A companion device shears the pin at the base for simple, complete removal.
Laboratory Equipment Corp. 3311

Evapo-Mix—A new solvent evaporator which combines a controlled-temperature-vacuum system with rotary vibration has been developed. Test tubes or centrifuge tubes taken directly from fraction collectors and other separation equipment are swiftly processed in groups of ten in this new and compact apparatus.
Laboratory Glass and Instruments Corp. 3312

Gamma Spectrometer—A new gamma spectrometer system designed to eliminate the "dark current" defect common to conventional systems is offered. It is said to offer better resolution over a wider range, and to provide greater precision in gamma spectroscopy than any other equipment now available.
Nuclear Measurements Corp. 3313

Push-Pull Testing—A new line of hydraulic "push-pull" universal testing machines has been developed. In addition to routine universal testing, this new machine can alternately apply tension and compression loads to the same specimen. Accurate dial indication of applied load is provided in either test direction on the large 28-in. diameter Selectorange dial.
Tinius Olsen Testing Machine Co. 3314

Insulation Tester—Features integral construction for nondestructive hipot testing a group of components or multiconductor cable. The table top cabinet houses a 0 to 10 kv a-c/d-c sensitive hipot tester, a central panel for control of testing sequence, and a heavy lucite interlocked door leading to a large compartment for the group of components to be tested. Panel controls enable instantaneous high-voltage switching from a-c to d-c testing at up to 10 kv.
Peschel Electronics, Inc. 3315

Atmospheric-Particle Monitor—New atmospheric-particle counting instrument designed for application to the continuous monitoring of outdoor air on atmospheres of indoor locations, such as ultraclean work areas, has been announced. It presents, on a strip-chart recorder, a permanent record of aerosols present in an over-all range from 0.3 μ to any desired upper limit. This record is differentiated into 15 subranges and recorded in sequence at intervals that can be predetermined in length.
Royco Instruments, Inc. 3316

Calibrator—A new precision calibrating unit designed to test tensile strength of larger diameter bolts and studs has been developed. Known as the Model K, the new unit is designed to measure bolt loads up to 225,000 lb; in general, it may be used with bolts and studs up to 2½ in. in diameter.
Skidmore-Wilhelm Mfg. Co. 3317

Puncture Tester—Now available is the TMI Beach puncture tester used for de-

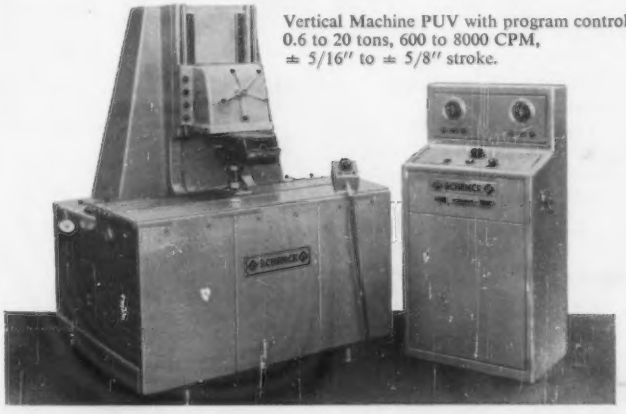
(*Continued on p. 84*)

Multi-Purpose SCHENCK
Fatigue Testing Machines
HIGH SPEED—COMPLETELY ADJUSTABLE FOR RESEARCH AND PRODUCTION TESTING

Exclusive Schenck fatigue testers offer more outstanding features. Test tensile strength, torsion, bending fatigue of any material, soft (rubber-plastics) or hard (steels). Basic push-pull action. High speed cycling permits rapid plotting of S-N curves. Built-in controls provide infinitely variable adjustment for frequency range, static and dynamic loads. Patented optical system measures loads, provides continuous visual inspection. Rubber mounts eliminate special foundations.

Horizontal Machine PB with program control.
3 to 100 tons, 280 to 4500 CPM, ± 1″ to ± 2″ stroke.

The Schenck PB horizontal (above) with long stroke and additional low speed drive applies rapid stress reversals with high loads—provides closest possible simulation of operating conditions. The Schenck PUV vertical (below) features many exclusives capacities of PB, but saves space through vertical design which makes it the ideal laboratory testing machine.



Vertical Machine PUV with program control.
0.6 to 20 tons, 600 to 8000 CPM,
± 5/16″ to ± 5/8″ stroke.

Schenck horizontal type PP (not illustrated).
2 to 60 tons, 2000 to 2600 CPM, ± 3/16″ to ± 9/32″ stroke.

Various gripping devices, load multipliers, heating-freezing chambers and program controls available for most, if not all, models.

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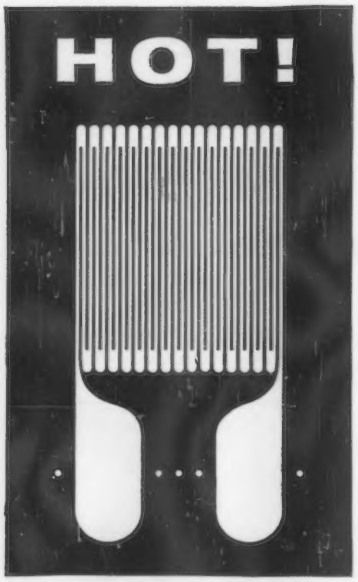

New Tatnall MetalFilm 102 higher-temperature backed strain gages from Bell

- Operating range to over 400°F surpasses previous strain gages by at least 50°F in all applications.
- Precision-designed and constructed for exceptional accuracy, repeatability and ruggedness.
- Ultra-thin (less than 0.0015 in.), with no integral leads, for high flexibility and conformability.
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- Wide range of sizes and configurations available, including standard configuration shown above, rosette and miniature types.

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CIRCLE 514 ON READER SERVICE CARD

LABORATORY ITEMS

(*Continued from p. 83*)

termining the resistance to puncture of corrugated board, fiber board, wall board, vulcanized fiber, plywood, and heavy liner.
Testing Machines, Inc. 3318

Electric Furnace Accessories—Six new functional accessory groups that let one model electric furnace perform several distinct operations are available. The accessories make the furnace useful as a salt-bath, oil-bath, melting, vertical-muffle or crucible furnace.
Thermo Electric Mfg. Co. 3319

Monitor—Designed for high-accuracy strain-gage instrumentation, the Model ENO-2 monitor panel reads bridge excitation voltage and bridge unbalance to a 0.1 per cent accuracy. This high degree of accuracy is obtained by comparing the voltage to be measured with an equal voltage that is selected from an ultrastable zener diode regulated supply. A portion of this reference is selected by means of a precision potentiometer and associated digital dial.
Video Instruments Co., Inc. 3320

Mobile Environmental Chamber—A new mobile environmental chamber with a range from −125 to +350 F has wide application in research, testing, and conditioning of parts and products. It is known as Model AF-1.5-125 + 350.
Webber Mfg. Co., Inc. 3321

Recording Instruments—A new line of temperature, pressure, and humidity recording instruments featuring ease of reading and dependable accuracy throughout the entire working range is announced. These instruments, contained in aluminum cases with gray hammertone finish, are available in 8-in. chart size with one to three pen systems; in 10-in. or 12-in. chart sizes with one to four pen systems; in hand-wound or electric chart drives for 12-hr, 24-hr, 7-day and 31-day revolution.
Weksler Instruments Corp. 3322

Catalogs & Literature

High-Pressure Compression Systems—Provides performance and engineering data on central compression systems supplying air, nitrogen, helium, or other gases for high-pressure pneumatic applications. Primarily for production, development, and test engineers, the catalog includes descriptions, typical applications, and construction features, together with performance charts.
Airdox Cardox Products Co., High-Pressure Pneumatics Div. 6180

X-Ray Spectrochemical Analysis—A folder discusses in some detail applications of X-ray spectrochemistry in industrial analysis, theory of the science, description of instruments, and data covering precision and accuracy of results.
Applied Research Laboratories, Inc. 6181

Environmental Testing—A new two-page, two-color, short-form catalog that describes and illustrates 13 different types of environmental test equipment is available. Among the test equipments featured are an acoustic-noise test system, auxiliary vibration (slippery) tables, and saw-tooth shock machines.
Associated Testing Laboratories, Inc. 6182

Laboratory Instruments—A new catalog, *Bulletin No. 757*, of laboratory instruments is available. Reference guide providing brief, concise descriptions of instruments for quality control, research, and other applications is included.
Beckman Scientific and Process Instruments Div. 6183

Ovens—Informative four-page, two-color *Brochure No. 6950* on special line of ultratemperature ovens is available. Ideal for applications requiring temperatures to 1300 F; capacities from 1 to 36 cu ft as well.
Blue M Electric Co. 6184

Metallographic Book—*Metal Digest*, Vol. V, No. 3 issue of the bi-monthly external house organ is available. Booklet is devoted to polishing cloths and abrasives for metallography, and actual swatches of polishing cloth, abrasive paper, and abrasive cloth are affixed to descriptions of the various products.
Buehler, Ltd. 6185

Vacuum Pumps—New 16-page, two-color *Bulletin No. 8-20* describes Roots high-vacuum pumps. Complete technical data is supplied.
Consolidated Vacuum Corp. 6186

Air Gage—A new 16-page catalog containing complete specifications and price information on the expanded line of Dearbornaire precision air-gaging instruments, elements, and related accessory equipment has been published.
Dearborn Gage Co., Air Gage Div. 6187

Print Paper Oscillographs—Kodak Linagraph direct print paper, a photographic material which provides an immediately visible record of certain oscillographic tracings, is described in a new leaflet now available. The photo recording paper yields an image without chemical processing and is capable of recording through a wide range of operating frequencies. It is manufactured for use in moving-mirror galvanometer oscillographs which employ an ultraviolet light source. Writing speeds of 100,000 in. per sec are possible.
Eastman Kodak Co. 6188

Sewage Testing Unit—A fully illustrated 16-page booklet, *Bulletin FS-242*, describes Fisher's recently-announced "packaged labs," unique units that contain everything necessary for modern waste-water analysis, from BOD incubators to red pencils.
Fisher Scientific Co. 6189

Conversion Table—In connection with Gardner color-difference meters, a conversion table for Rd/L values for the convenience of those who report the magnitude of color-difference in terms of NBS units is offered.
Gardner Laboratory, Inc. 6190

Laboratory Newsbook—New house organ features developments in laboratory apparatus and equipment.
Labasco, Inc. 6191

X-Ray Chart—A new 11½ by 22 in. wall chart showing ten basic X-ray techniques used today for industrial quality control and scientific research is available.
Philips Electronic Instruments 6192

(*Continued on p. 86*)

Polish metallurgical samples easier, better, more uniform

with

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—whether it's one or a number of specimens to be polished, SYNTRON Vibratory Lapping-Polishing Machines will produce a metallographic finish for an electron microscope or brush analyzer examination.

Gentle, electromagnetic vibration moves the specimens smoothly around the pan, over abrasive cloth or polishing felt cloth. Abrasive cloths are removable.

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now, a completely automatic laboratory furnace

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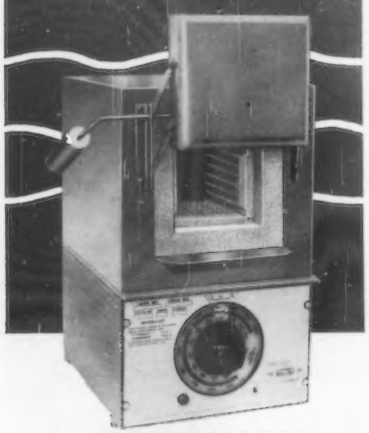

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Just dial desired temperature. This electric furnace, *specifically designed for laboratory use*, automatically holds preset temperatures within close limits by means of a potentiometric control system. Practically immune to vibration, dust, dirt to give long, trouble-free service. Rigid, braced construction . . . long-life heating elements embedded in interchangeable plates that give fast, even heat distribution. Chamber surrounded by high-grade, multiple-type insulation. Chamber size 4" x 3¾" x 9". Operating temperatures to 1650°F continuous, 1900°F intermittent. 115 and 230 volts. Price complete, $247.50. Write for literature and name of nearest dealer.

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CATALOGS & LITERATURE

(*Continued from p. 84*)

Polarograph—*Bulletin P* describing in detail four polarographs has been released. This 12-page polarographic booklet colorfully illustrates these instruments and their accessories and discusses their operations and applications.
E. H. Sargent & Co. 6193

Laboratory Apparatus—*What's New for the Laboratory*, 38th in the series, features new laboratory items including the new Ainsworth vacuum automatic recording balance.
Scientific Glass Apparatus Co., Inc. 6194

Soil Catalog—Containing 316 pages, almost three times as many as last year's edition, the new 1960 catalog describes over 3400 different items ranging from a small pocket-sized soil penetrometer to completely equipped mobile laboratories and nuclear testing equipment. The catalog also features approximately 1500 illustrations, referenced to ASTM and AASHO specifications.
Soiltest, Inc. 6195

Friction and Slip Tester—Now available is a two-page brochure which illustrates the new TMI friction and slip tester. The brochure describes the processes involved in testing the friction and slip characteristics and qualities of paper, paperboard, and corrugated media.
Testing Machines, Inc. 6196

Stiffness Testers—A data sheet illustrating and describing three different types of stiffness testers is available. The testers are used to evaluate the stiffness and resilient qualities of plastics, leather, paper, cardboard, light metallic sheet, foil, wire, and other flexible materials.
Testing Machines, Inc. 6197

Thermocouple Terminal—A new illustrated *Bulletin No. 28* describing a new line of weatherproof multi-junction thermocouple terminal boxes is now available. These boxes, with cellular neoprene gasketed covers, provide ideal protection for the termination of "Thermo-Cable" (multiconductor thermocouple extension cable) against the effects of oil, dust, dirt, humidity, or any other contaminating environment.
Thermo Electric Mfg. Co. 6198

Vacuum Pump—New leaflet describing the Series 150 electronic high-vacuum pumps available under the trade name UlteVac has been announced. This new publication illustrates the Model 150 together with corresponding power supply which operates the units in general laboratory application as well as in vacuum-tube processing and thin-film work. A calibration curve is included with pump current plotted against pumping pressures.
ULTEK Corp. 6199

Vibration Test—A 4-page *Bulletin No. 59–5* describes system performance, components, and accessories. A complete description and dimensions of the 400-lb force shaker are given.
Unholtz-Dickie Corp. 6200

New Catalog Supplement—The new Will TABLOG, featuring for the first time Kimble volumetric glassware with Teflon stopcocks—a brand new line of precision - made Kimax manufactured under Fischer and Porter Patents—has been announced.
Will Corp. 6201

Instrument Company News

Baldwin-Lima-Hamilton Corp., Waltham, Mass.—A new licensing and marketing agreement between the Electronics and Instrumentation Div. of Baldwin-Lima-Hamilton Corp., Waltham, Mass., and High Temperature Instruments Corp., Bala-Cynwyd, Pa., has been announced by the two firms. The new arrangement gives Baldwin-Lima-Hamilton exclusive distribution rights to the high-temperature wire and mono-filament strain gages, micro-miniature thermocouples, high-temperature cements, and other products developed and handled by High Temperature Instruments.

Plas-Tech Equipment Corp., Natick, Mass.—Predicting the behavior of many plastic products is going to be a lot easier as a result of studies made at the new Plastics-Research Center opened by Plas-Tech Equipment Corp. This was made evident when Melvin Silberberg, president of Plas-Tech, demonstrated two of the testing machines developed by his company for measuring the performance of rubber (elastomers) and other plastics under high rates of stress application. Besides designing and building specialized test equipment for the plastics industry, Plas-Tech is applying the expanded facilities of its new Plastics-Research Center to a broad program of services in plastics technology.

News of Laboratories

Atlantic Research Corp., Alexandria, Va.—A new service to producers and users of rocket materials has been announced by the Atlantic Research Corp., Alexandria, Va. Routine testing of various material candidates for rocket and missile applications and other materials requiring high-temperature tolerance and resistance to high-velocity gas flow is being offered, utilizing both standard solid propellants and the new high-impulse aluminized propellants.

Harris Laboratories, Inc., Lincoln, Nebr.—Availability of a new illustrated brochure describing special and routine laboratory services was announced by Harris Laboratories, Inc., 816 "P" Street, Lincoln 8, Neb. In addition to standard services in research and testing for the food, pharmaceutical, and agricultural industries, several unusual facilities are listed.

Metal Control Laboratories, Inc., Huntington Park, Calif.—Has announced the purchase of Pacific Testing Laboratories, Inc., of Van Nuys, Calif. Pacific Testing Laboratories is a well-known firm specializing in fatigue testing and research. Pacific's equipment and personnel will be moved to the Metal Control Laboratories location in Huntington Park.

Schaevitz Engineering, Pennsauken, N. J.—Establishment of commercial testing laboratories for the testing and calibration of industrial instruments is announced by Herman Schaevitz, president, Schaevitz Engineering. To be known as the Schaevitz Testing Laboratories, the new company is the third in the organization of Schaevitz companies, and has been designed to expand continuously to keep pace with the rapidly changing requirements of industry.

Other Societies' Events

February 1–5—**American Institute of Electrical Engineers,** Winter Meeting, New York, N. Y.

February 2–4—**Society of the Plastics Industry,** Reinforced Plastics Div., Edgewater Beach Hotel, Chicago, Ill.

February 4–6—**American Society for Metals,** Fairmont Hotel, San Francisco, Calif.

February 14–18—**American Institute of Mining, Metallurgical, and Petroleum Engineers,** Hotels McAlpin and Statler, New York, N. Y.

February 18–20—**National Society of Professional Engineers,** Winter Meeting, Broadview Hotel, Wichita, Kans.

February 21–24—**American Institute of Chemical Engineers,** Biltmore Hotel, Atlanta, Ga.

February 22–25—**Technical Association of the Pulp and Paper Industry,** Annual Meeting, Commodore Hotel, New York, N. Y.

February 29–March 4—**Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy,** Penn-Sheraton Hotel, Pittsburgh, Pa.

March 7–8—**Steel Founder's Society of America,** Annual Meeting, Drake Hotel, Chicago, Ill.

March 14–17—**American Concrete Inst.,** Annual Meeting, Commodore Hotel, New York, N. Y.

March 14–16—**American Railway Engineering Assn.,** Annual Meeting, Sherman Hotel, Chicago, Ill.

March 14–18—**National Association of Corrosion Engineers,** Annual Conference and Show, Memorial Auditorium, Dallas, Tex.

March 21–24—**Institute of Radio Engineers,** National Convention, New York, N. Y.

March 24–25—**Textile Research Inst.,** Annual Meeting, Hotel Commodore, New York, N. Y.

March 31–April 2—**Scientific Apparatus Makers Assn.,** Annual Meeting, Boca Raton Hotel, Boca Raton, Fla.

April 3–8—**1960 Nuclear Congress,** New York Coliseum, New York, N. Y.

April 4–6—**American Oil Chemists' Society,** Annual Meeting, Baker Hotel, Dallas, Tex.

April 19–21—**Building Research Inst.,** Spring Conference, Statler-Hilton Hotel, New York, N. Y.

April 19–21—**American Society of Lubrication Engineers,** Annual Meeting, Netherland-Hilton Hotel, Cincinnati, Ohio

April 21–28—**American Society of Tool Engineers,** Tool Show and Annual Convention, Detroit, Mich.

April 24–28—**American Ceramic Society,** Hotel Bellevue-Stratford, Philadelphia, Pa.

April 25–27—**Association of Iron and Steel Engineers,** Spring Conference, Sheraton Hotel, Philadelphia, Pa.

April 25–29—**American Society for Metals,** 2nd Southwestern Metal Exposition and Congress, Dallas, Tex.

April 25–29—**American Welding Society,** Annual Meeting and Exposition, Hotel Biltmore, Los Angeles, Calif.

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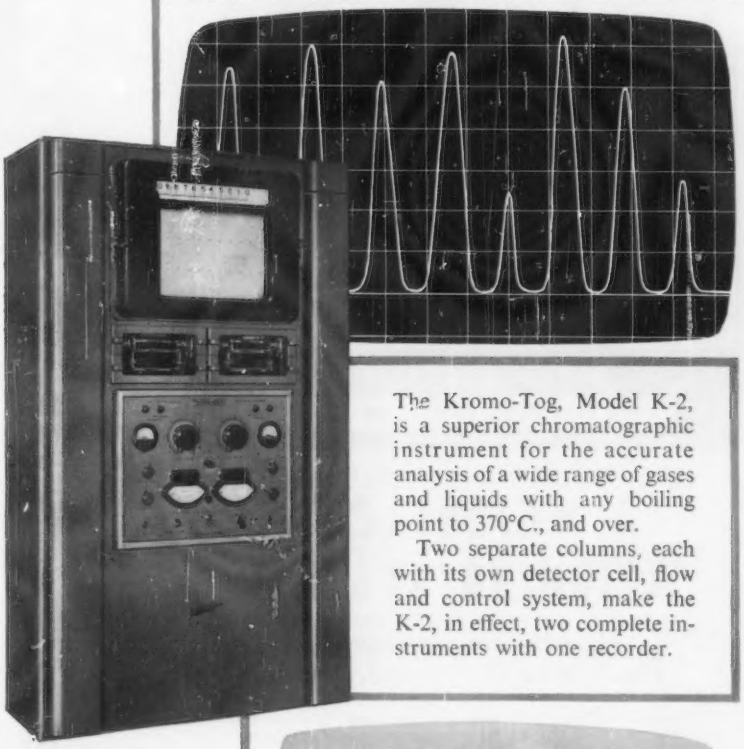

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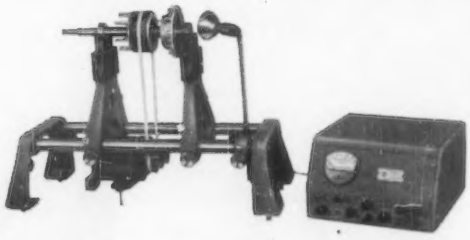

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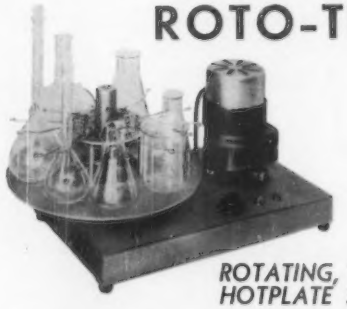

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Federal Government Standards Index Changes

THE FEDERAL Supply Service of the General Services Administration is charged with the responsibility for establishing specifications to be used by the Federal Government for Procurement of materials and supplies. The GSA issues an annual Index of Initiation of Federal Specifications Projects, and monthly supplements.

The items listed below appeared in Supplement 9 for December 1959.

INITIATIONS

Title	Type of Action	Symbol or Number	FSC Class	Assigned Agency & Preparing Activity
Tolerances for Aluminum Alloy and Magnesium Alloy Wrought Products	Rev.	Fed. Std. No. 245a	...	DOD-Navy-Aer
Antifreeze, Ethylene Glycol, Inhibited	Am. 1	O-A-548a	6850	DOD-Army-Ord
Cement, Rubber (Artists' and Photographers' and Cold-Patching)	Am. 3	ZZ-C-191a	8040	GSA-FSS
Fencing, Chain-Link Fabric	Rev.	RR-F-191b	5660	DOD-Army-CE
Gases, Fuel, Liquefied Petroleum (Butane, Propane Mixture)	New	BB-G-110	9120	DOD-Navy-Docks
Hose, Plastic, Garden	New	L-H-00520 (COM-NBS)	4720	COM-NBS
Hydraulic Fluid, Nonpetroleum Base, Automotive	Am. 1	VV-H-910	9150	DOD-Army-Ord
Paperboard, Wrapping, Cushioning	Am. 2	PPP-P-291a	8135	GSA-FSS
Soap, Laundry, Powdered	Am. 2	P-S-596c	7930	DOD-Navy-Ships
Steel, Carbon, Plate	Rev.	QQ-S-635	9515	DOD-Navy-Ships
Steel, Sheet and Strip, Low Carbon	New	QQ-S-698	9515	DOD-Navy-Ships
Steel, Sheet and Strip, Medium Carbon	New	QQ-S-700	9515	DOD-Navy-Ships
Steel, Strip, Carbon, Cold Rolled, Untempered, Spring	New	QQ-S-777	9515	DOD-Navy-Ships
Tape, Pressure-Sensitive Adhesive, Paper, Drafting	Rev.	UU-T-93c	7510	GSA-FSS
Triphenyl Phosphate (for Use in Organic Coatings)	New Rev.	TT-T-662b	6810	GSA-FSS

TITLE CHANGES

Title	Type of Action	Symbol or Number	Former Title
Boxes, Wood, Household Goods	Rev.	PPP-B-580a	Crates, Wood, Household Goods
Flooring, Vinyl Plastic	New	L-F-450a	Tile Floor, Vinyl-Plastic
Washcloth, Cotton, Terry	New	DDD-W-80	Cloths; Wash, Terry Cloth

PROMULGATIONS

Title	Type of Action	Symbol or Number
Aluminum Alloy; Bars, Rods, and Shapes; Extruded; 6061 and 6062	Am. 1	QQ-A-270a
Bolt (Square-Neck, Machine, Ribbed-Neck, Finned-Neck, Tee-Head, Key-Head) (Round-Head)	Am. 1	FF-B-584a
Cans, Fiberboard and Paperboard (with Paper and Metal Ends) (Superseding PPP-C-0055 (GSA-FSS))	New	PP-C-55a
Cloth, Cotton, Chambray (Superseding CCC-C-00231b (GSA-FSS) & CCC-C-231a)	Rev.	CCC-C-231c
Cloth, Cotton, Sheeting (Unbleached, Bleached, and Dyed) (Superseding CCC-C-00432 (GSA-FSS) & CCC-S-281a)	New	CCC-D-950
Concrete, Ready-Mixed (Superseding SS-C-00618 (COM-PR))	New	SS-C-618a
Cupric Sulfate, Pentahydrate, Technical (Superseding O-C-828)	Rev.	O-C-828a
Drum, Metal Shipping, Steel (over 12 and under 55 Gallon) (Superseding PPP-D-00705 (COM-BDSA))	New	PPP-D-705a
Dyeing and Aftertreating Processes for Cotton Fabrics (Superseding CCC-D-00427 (Army-QMC)	New	CCC-D-950

(*Continued on p. 91*)

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P. R. F. External	0-3000 cps
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CIRCLE 527 ON READER SERVICE CARD

FEDERAL GOVERNMENT STANDARDS

(*Continued from p. 89*)

Enamel, Alkyd, Lusterless (Superseding TT-E-527)	Rev.	TT-E-527a
Hydrochloric Acid (Muriatic), Technical (Superseding O-H-00765 (GSA-FSS) & O-A-86)	New	O-H-765a
Isobutyl Alcohol (for Use in Organic Coatings)	New	TT-I-730
Lacquer, Lusterless, Obliterating	New	TT-L-40
Nitric Acid, Technical (Superseding O-A-0088a (GSA-FSS) & O-A-88)	New	O-N-350
Paper, Blotting (Superseding UU-P-0063b (GSA-FSS) & UU-P-63a)	Rev.	UU-P-63c
Paper, Book (Superseding UU-P-00465b (GSA-FSS) & UU-P-465a)	Rev.	UU-P-465c
Pigment, Cadmium-Yellow (Cadmium Lithopone), Dry (Superseding TT-C-0083a (GSA-FSS) & TT-C-83)	New	TT-P-342
Pigment, Copper-Phthalocyanine-Blue, Dry	Am. 1	TT-P-355
Pigment, Zinc-Dust (Metallic-Zinc-Powder), Dry	Am. 1	TT-P-460
Polish, Automobile, Liquid	Am. 1	P-P-546a
Sodium Carbonate-Sodium Bicarbonate Mixture (Superseding P-S-00641e (GSA-FSS) & P-S-641d)	Rev.	P-S-641f
Sweeping Compound Absorbent Material and Water	Am. 2	P-S-865a
Tape, Electric Wire-Flexible Insulating Sleeving Marking Machine (Foil, Wire Identification, Marking)	New	GG-T-25
Thinner, Dope and Lacquer (Cellulose-Nitrate) (Superseding TT-T-266a)	Rev.	TT-T-266b
Tile, Cork (Superseding LLL-T-00431a (COM-NBS) & LLL-T-431)	Rev.	LLL-T-431b
Tool Steel, Alloy	Am. 1	QQ-T-570

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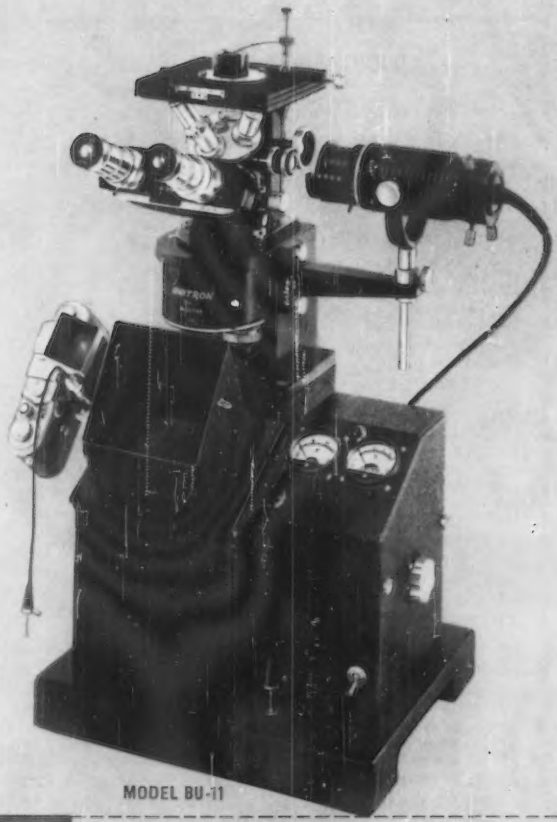

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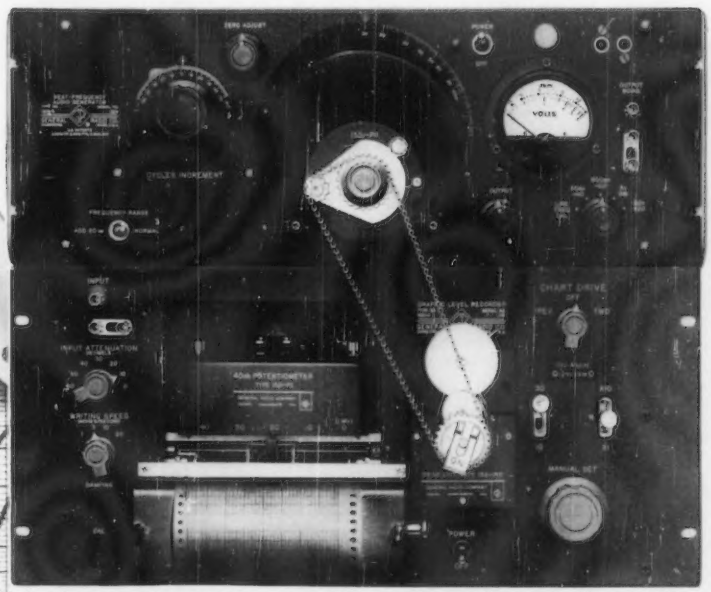

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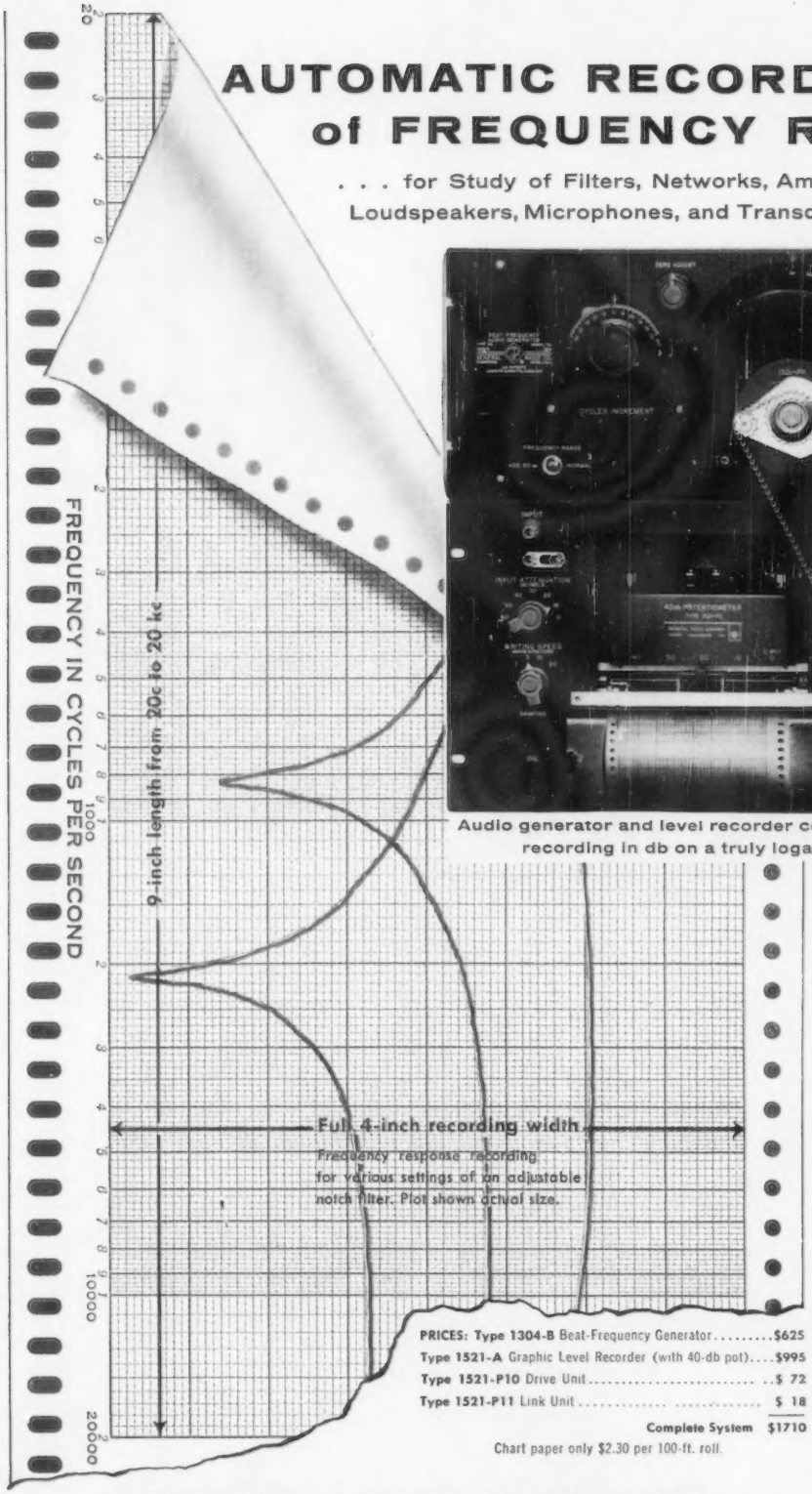
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Pen Writing Speed: 20 in/sec maximum with 40-db Pot (200 db/sec) with less than 1-db overshoot. Slower speeds (1, 3, or 10 in/sec) selected by panel switch to provide mechanical filtering of rapidly fluctuating levels.

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Recorder Accuracy: Static accuracy better than 0.4% of full scale. Fast servo system with low overshoot provides excellent dynamic accuracy.

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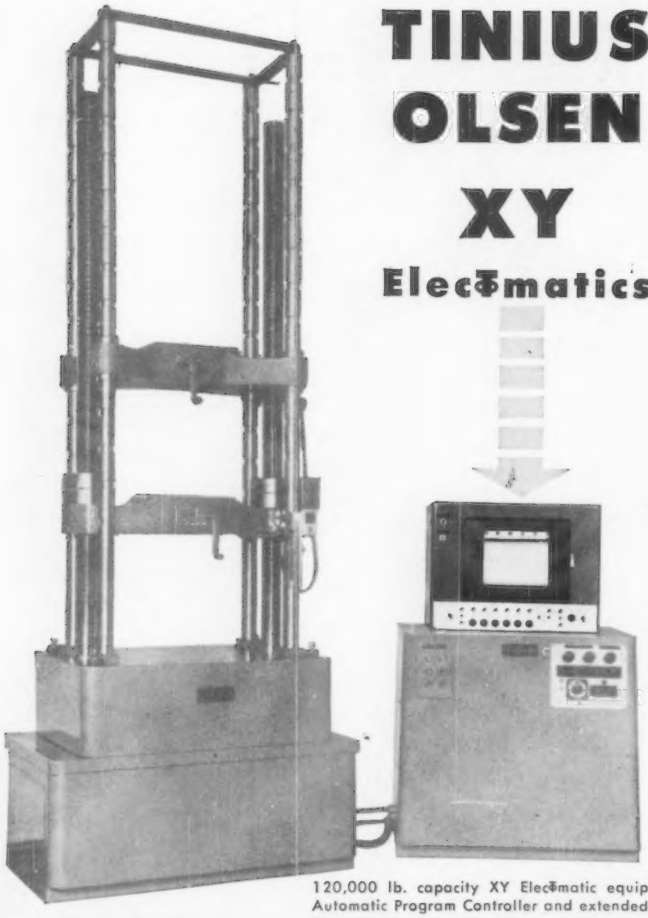

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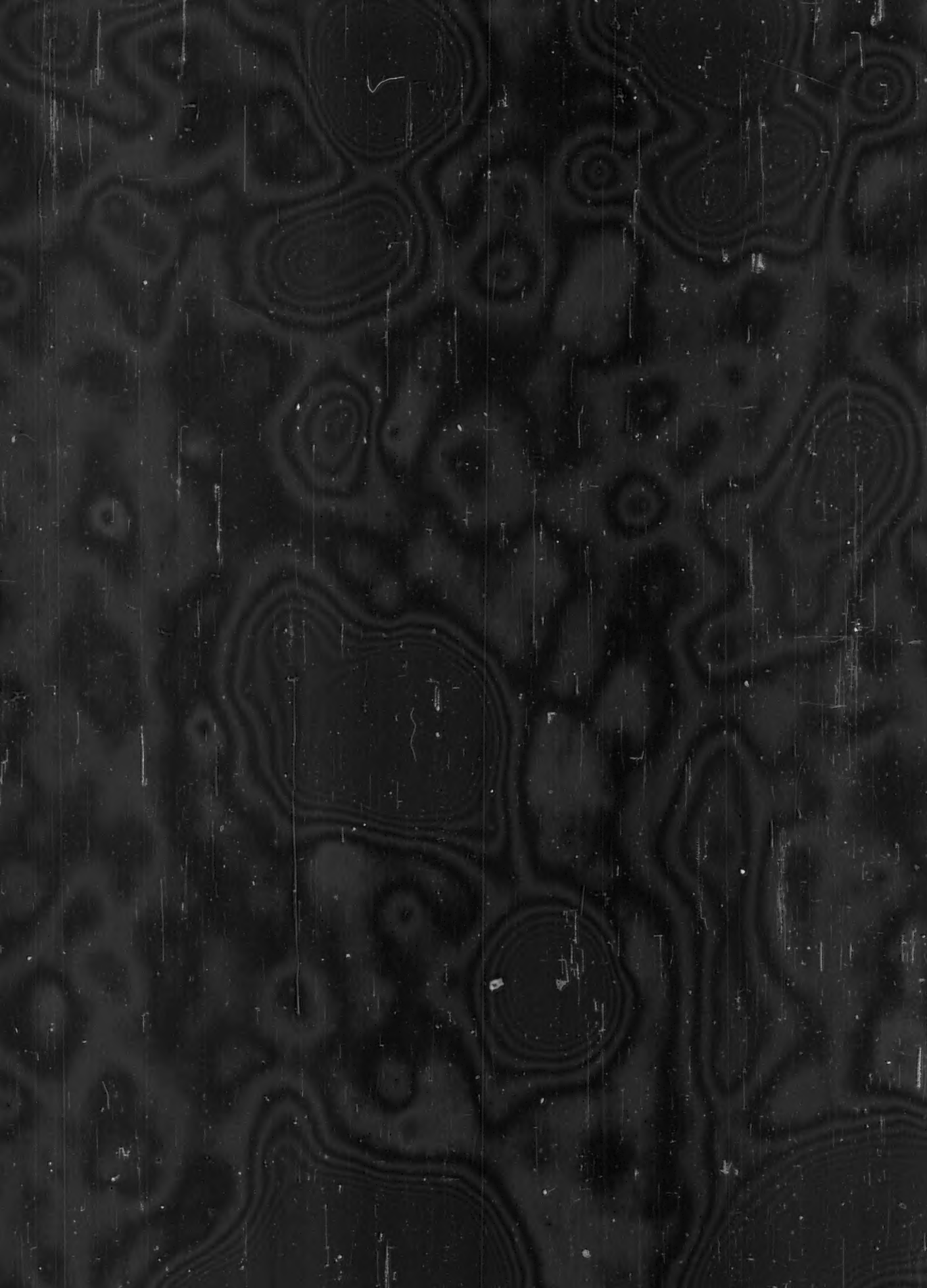
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